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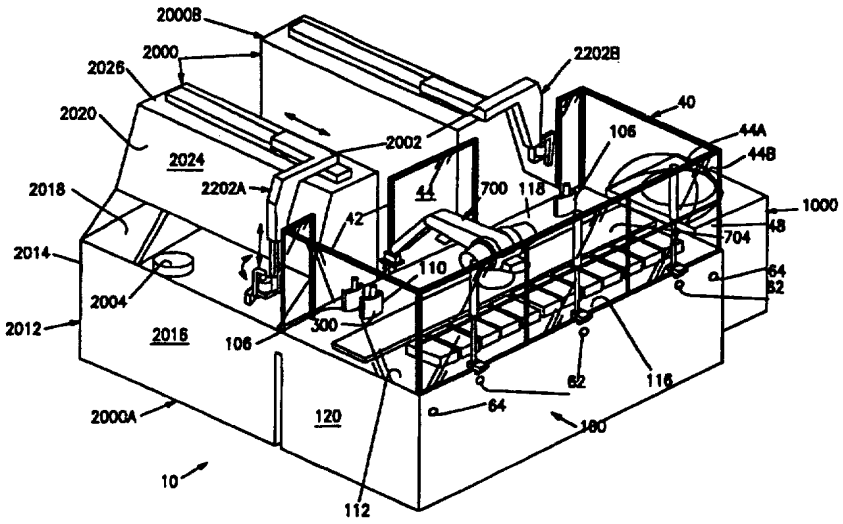

(57) Abstract

A system for a clinical lab that is capable of automatically processing, including sorting, of multiple specimen containers. The system comprises a central controller, a workstation (100), one or more analyzers (2000), and an automated centrifuge (1000). The workstation (100) has automatic detectors for detecting the presence of a holder (14) holding specimen containers (12). The workstation (100) has a bar code reader for reading bar codes on the containers. The system has a transport subsystem, preferably a workstation robotic arm (700) and an analyzer robotic arm (2002) for transporting the specimen containers (12), moving them to and from the workstation (100), to and from the analyzers (2000), and to and from the centrifuge (1000). The centrifuge is loaded with buckets (1200) containing specimen containers (12). The workstation (100) can be provided with a balance system (800) for balancing the weight of the buckets (1200) used. The workstation (100) can also have a decapper (900) for automatically removing caps from the specimen containers.

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AUTOMATED SAMPLE PROCESSING SYSTEM

BACKGROUND

The present invention relates generally to systems for the automation of laboratory tests, and particularly testing of biological specimens.

Laboratory testing has changed and improved remarkably over the past 70 years. Initially, tests or assays were performed manually, and generally utilized large quantities of serum, blood, or other biological fluids. However, as mechanical technology developed in the industrial workplace, similar technology was introduced into the clinical laboratory. With the introduction of new technology, methodologies were also improved resulting in improved quality of the results produced by the individual instruments, and a decrease in the amount of specimen required to perform each test.

Instruments have been developed to increase the efficiency of testing procedures by reducing turnaround time and decreasing the volumes necessary to perform various assays. Exemplary of such instruments are the Synchron$_{TM}$ line of automated analyzers available from Beckman Instruments of Fullerton, California. Such instruments are capable of automatically analyzing a large number of blood specimens and a large number of analytes, providing reliable, accurate, and fast analysis of specimens.

There remains room for improvement in the operations of clinical laboratories, in spite of the advances that have been made. For example, significant labor is still required for sample preparation. Sample preparation can include the sorting

of specimens for processing, centrifugation, and removal of the caps of containers containing the specimens. Centrifugation requires loading multiple specimen containers, which are typically test tubes, into centrifuge buckets, balancing the weight of the buckets so the centrifuge is balanced, loading the buckets into the centrifuge, closing the centrifuge lid, centrifuging, opening the lid, removing the buckets, and then removing the test tubes from the buckets. All these operations are labor intensive, increasing the cost of laboratory analysis. Moreover, these labor intensive steps can lead to operator error. Also, human involvement always involves the risk of contamination of specimens by the operator, and exposure of the operator to dangerous biological substances.

There have been attempts to improve automation include the use of conveyor systems for conveying specimens to analyzers, such as those described in U.S. Patent Nos. 5,178,834 and 5,209,903. A difficulty with using conveyor systems is that they generally are part of a total integrated system, which system includes special analyzers and other handling equipment. Thus a clinical laboratory that wishes to switch to a conveyor system may need to replace its entire existing system, with attendant high capital investment and significant training expense for the operators.

Another common problem in clinical laboratory systems is how to deal with "STAT" specimens. These are specimens that need immediate attention. For example, specimens from patients in the emergency room often require "STAT" analysis so attending physicians can determine the cause of the medical emergency. Present clinical systems currently depend on operator intervention to interrupt the normal flow of work to be certain that the STAT samples get immediate attention. However, in the hustle and bustle of a clinical laboratory these STAT samples and specimens do not always get the immediate attention they need.

Laboratory centrifuges of the prior art typically have a high-speed motor-driven spindle, a plurality of holders for test-tubes, test-tube racks and/or vials being provided at respective angularly spaced stations of a head assembly of the spindle, the head assembly being located within a tub-shaped cavity and surrounded by a safety ring, the centrifuge also having a safety-latched door for covering the cavity during operation of the spindle. The spindle is driven at a selected speed which can be as high as from about 3600 RPM up to about 100,000 RPM.

A number of challenges are associated with automation of centrifugation. For example:

1. It is desired to bypass centrifuging in some cases;

2. Access to the centrifuge is impeded by the presence of a protective cover, which typically swings vertically between open and closed positions;

3. Inordinate expense is associated with automating the cover and protecting against persons being injured during movement thereof;

4. It is necessary to have the centrifuge balanced within approximately 10 grams before high-speed operation can commence; and

5. Many processes are inordinately burdened by the time required for spinning the samples, particularly when lengthy periods are needed for loading and unloading the centrifuge, for programming spin cycles, and for accelerating and decelerating the centrifuge.

In some centrifuges of the prior art, a spindle head can be indexed to one of a plurality of rest positions for facilitating loading and unloading at corresponding angularly spaced receptacle stations of the spindle head assembly. However, these centrifuges are undesirably complex and expensive to provide in that separate motors and controls are used for the indexing and for high-speed operation; a further consequence being degraded high-speed performance resulting from added inertia that is associated with the indexing motor.

Accordingly, there is a need for a system that can automate the sample handling and sample preparation process, including the centrifugation for analytical procedures, including in particular, clinical laboratories. It is desirable that the system can be used with existing equipment, i.e., existing equipment does not need to be replaced, and can be used with a wide variety of existing analytical equipment. Further, system throughput should be only minimally affected by specimens requiring centrifugation. Moreover, it is desirable that the system recognize and expeditiously handle STAT samples, minimize the health risks associated with contacting biological samples, and minimize the chance that specimens will be inadvertently contaminated by operator error.

SUMMARY

The present invention provides a system that meets these needs. The present system is based upon a modular workstation that can automatically prepare biological specimens for further processing by a large variety of analytical equipment, without having to replace existing analytical equipment. The system can sort incoming samples, and prioritize STAT samples. As needed, incoming samples can be automatically centrifuged, decapped, and transported to selected analytical equipment. The system can be automatically controlled through the use of a central controller. The system provides efficient, high throughput and fast turnaround analytical results, with decreased chance for operator error and decreased exposure of operators to biological substances.

Typically, specimens to be automatically processed are in multiple containers, such as test tubes, which can be capped. Each of the containers is provided with container identification indicia, such as a bar code. The containers are in one or more holders such as sectors and/or racks that can have identification indicia thereon.

In accordance with one aspect of the present invention, a processing system includes (i) the central controller, (ii) a workstation having subsystems for sorting, preparing, and transporting the containers, (iii) a centrifugation system for centrifugation of selected specimens, and (iv) at least one analyzer for selectively analyzing specimens. Not only is this overall system believed to be novel and inventive, it is also believed that the subsystems of the overall system, as well as particular mechanical components of the system, are novel and inventive.

Central Controller

The central controller, which can be provided as part of the workstation, comprises memory storage and a data input element for inputting processing instructions into the memory storage for the processing of each container according to the container identification indicia. Based on instructions in the central controller, each container can preferably be processed as follows:

(a) Sorting only, i.e., the workstation is used only for sorting containers for further processing;

(b) Sorting and centrifugation;

(c) Sorting, centrifugation, and decapping;

(d) Sorting, centrifugation, decapping and analysis;

(e) Sorting, decapping and analysis (for samples not requiring centrifugation); and

(f) Sorting and analysis (for samples not requiring centrifugation and automated decapping).

The central controller can be provided with a process supervisor having a programmed detect input step for determining introduction of containers at an input location on the workstation, a container select step in which detected containers are selected for processing, an identification step for defining process components for each selected container according to the container identification indicia, and a process select step for initiating the defined process components being one or more of sorting, centrifugation, decapping, and analysis.

Workstation

The workstation is provided with detectors for detecting the presence of a holder in the system. The detectors have an output element for signaling the presence of a holder to the central controller. The workstation has an indicia reader, such as a bar code reader, for reading the container identification indicia. The indicia reader is provided with an output element for providing container identification indicia to the central controller. Preferably the indicia reader is also effective for signaling holder identification indicia to the central controller.

The workstation also includes a container sorting subsystem which has a data input element in communication with the central controller for receiving instructions from the central controller for sorting containers for selective processing according to the processing instructions stored in the central controller memory storage. The container sorting system also includes a plurality of sort sites for placement of containers according to their processing instructions.

Typically the workstation includes multiple input locations for initial placement of the containers by an operator, each of the input locations having one of the detectors. Preferably at least one of the locations is selected for priority containers, i.e., STAT specimens, so that the central processor, when signaled by the detector

output element about the presence of a priority container, provides instructions for priority processing of priority containers.

The workstation typically comprises a table with positioners, such as posts, for positioning the holders and centrifuge receptacles in predetermined locations. The table can be provided with below surface detectors, such as reed switches, for detecting the presence of a holder on the table. A workstation robotic arm is supported on the table, and is generally provided with the indicia reader, which can be a bar code reader. The table has an analyzer delivery site for placement of holders for analysis by the analyzer, and an analyzer receiving site for receiving analyzed samples from the analyzer. Preferably the workstation is provided with a shield system for selectively blocking operator access such as would interfere with system operation. The shield system can include a partition that encloses the top of the workstation and having openings for passage of the analyzer robotic arms, an enlargement for passage of receptacles to the centrifuge, and an interlocked access door. The access door can be a sash door having an actuator being responsive to the central controller, and an operator input device for signaling access requests to the central controller, the controller being operative for appropriately inhibiting operation of the workstation robotic arm and then activating the actuator for opening the door. Preferably a base of the table has a modular plurality of bulkheads that are connected by a pair of beams and a rail of the robotic arm track. Preferably the rail provides a high capacity air reservoir for the system.

Two different types of holders can be used, and different types of positioners for the different types of holders can be used. For example, a first holder, such as a sector, can be used for containers to undergo processing, wherein the first holders are transported by the transport system. Second holders, such as racks, can be used where the containers of the second holder are transported by the transport system individually for sorting. It is preferred that the holder positioners for the second holders are closer to the transport system than are the holder positioners for the first holders for minimal movement of the transport system.

Typically the table is located proximate to one of the analyzers. Preferably the section of the table closest to the analyzer is used for holding containers for delivery to the analyzer. The table can have an input side for receiving containers for

processing, the input side being opposed from the analyzer side, with a transport path for the workstation robotic arm located between the input side and the analyzer side.

Centrifugation System

The centrifugation system includes an automated centrifuge which is loaded with multiple receptacles, also known as baskets or buckets, each bucket receiving multiple containers. The centrifuge includes a motor coupled to a spindle that receives the buckets, a controller, and optionally, a lid, and a lid drive. The centrifuge controller indexes or stops the spindle at selected positions for automated placement and removal of the buckets in response to signals from the central controller. The lid has a closed position and an open position, and the lid drive opens and closes in response to instructions from the centrifuge controller.

Before the loaded receptacles are placed in the centrifuge, preferably they are balanced in a balance system. The balance system, which can be an included part of the workstation, comprises a scale having sites for receiving and holding a plurality of container receptacles, and a balance controller for selectively depositing containers in cavities of the receptacles while correlating incremental weight changes with the locations of each deposit for equalizing weight in pairs of the receptacles. The balance controller can be implemented as a balance program within the central controller, the balance program maintaining a database of container locations and associated weights, and directing the robotic arm for depositing the containers. Preferably the balance system also includes a supply of dummy loads, i.e., dummy test tubes, the balance controller being operative for selectively depositing selected dummy loads in receptacles for limiting weight variations between receptacles. Preferably the dummy loads are weighted for limiting the weight variations to not greater than 10 grams between members of each pair of receptacles.

A preferred centrifuge according to the present invention includes a base; a spindle head supported relative to the base for supporting and spinning an angularly spaced plurality of fluid receptacles about a vertical axis; a spindle motor coupled to the spindle head; a rotary encoder associated with the motor for producing an index signal and a plurality of position signals for each revolution of the spindle shaft; a driver for powering the spindle motor in response to an external signal; an enclosure supported by the base for enclosing the head means during the spinning, an upper portion of the enclosure having an openable access lid therein for accessing the fluid samples; a

positioner coupled to the access lid for horizontal translation thereof between open and closed positions; a lid position sensor for signalling the closed position of the lid; and a controller for signalling the driver and the door positioner in response to the encoder, the door position sensor, and external signals.

Centrifuge Controller

Preferably the centrifuge controller is operative for (a) receiving an storing a centrifuge spin profile including a rotor spindle speed and duration; (b) indexing the rotor for advancing a selected one of the sample stations into an access position; (c) spinning the rotor in accordance with the cycle profile; and (d) stopping the rotor with a predetermined sample station at the access position. Preferably the same spindle motor is operative for both indexing and spinning the rotor for avoiding deleterious addition of inertia to the spindle head. Preferably the controller is further operative for implementing programmed acceleration and velocity of the spin profile together with a distance of rotation, the distance of rotation including a first distance corresponding to spin rate and duration, and a second distance corresponding to acceleration to the spin rate and deceleration to rest. Preferably the distance of rotation further includes a distance interval from the indexed position to the predetermined sample station for smooth deceleration from the spin rate to rest with the sample station at the access position.

Preferably the lid positioner is frictionally coupled to the lid for preventing injury in case if inadvertent contact with the lid during movement thereof. The lid positioner can include a drive wheel biasingly contacting the lid for movement thereof while limiting application of driving force thereto.

Decapper System

Before centrifuged containers are analyzed, they can be decapped in the decapper system, which can also be an included part of the workstation. The decapper system includes a receiver for clampingly holding a container, a yoke member movably mounted relative to the receiver and having means for holding a cap seated in the container, a translator for laterally moving the yoke member between open and closed positions thereof, and an elevator for raising the yoke member, in the closed position thereof, relative to the receiver to thereby remove the cap.

Preferably the decapper system also includes a collector for receiving caps from the yoke member, and an unloader for transferring removed caps from the

yoke member to the collector. The means for holding the cap can include an upwardly facing ledge portion of the yoke for engaging an outwardly extending shoulder surface of the cap, the ledge portion extending under the cap in the closed position. The unloader can be implemented by a post fixedly located relative to the receiver, in combination with programmed operation of the translator and the elevator for locating the yoke member in the open position thereof with the removed cap aligned above the post, and lowering the yoke member for engagement of the cap with the post, thereby stripping the cap from the yoke member. In a preferred alternative to the ledge portion, the yoke member has a powered clamp mechanism for gripping the cap, and the unloader can be a plunger biasingly supported on the yoke, in combination with programmed operation of the translator for loading the plunger by the cap prior to activation of the gripping mechanism, the cap being ejected by the plunger upon release of the clamping mechanism.

Preferably, the decapper further includes a guide for directing the stripped caps into the receiver. Also, the decapper further includes a cap sensor for detecting and signalling the passage of caps into the receiver for verifying proper decapping.

Preferably the receiver is controllably rotatable for removal of threaded caps. The receiver can include an inflatable bladder within a rigid member and fluid-connected through a control valve to a pressure source for selectively gripping the container. In a preferred alternative, a flexible sleeve having a closed bottom encloses a portion of the container within a rigid member, a jaw mechanism in the rigid member selectively clamping the container through the sleeve, the sleeve advantageously preventing spillage in case of a broken container.

The system of the present invention is useful with a wide variety of specimens, and generally is used with biological specimens such as human blood samples. However, it can also be used for non-biological specimens.

Analyzer

Typically the system comprises two analyzers, i.e., a single workstation centrifuge can serve two analyzers. However, the system can be used with one analyzer or more than two analyzers. Typically each analyzer comprises a mechanism for selectively performing at least two different analyses on a specimen, and an analyzer controller in communication with the central controller, so the central controller can

instruct the analyzer controller as to what analysis to perform for each specimen. Each analyzer also includes an output system for providing analysis results to memory of the central controller. Typically each analyzer output system has an output element for providing analyzer availability information to the central controller, and the central controller has means for selectively determining which analyzer each specimen that is to undergo analysis is analyzed by.

A typical analyzer has opposed sides, a front, a top, and a back, the top having analytical equipment thereon and being accessible from the front by a user. Preferably the workstation is proximate to one of the sides of the analyzer without any obstruction of the front of the analyzer. The workstation has a front, a back, and opposed sides, and preferably the back of the workstation is proximate to the side of the analyzer. When a centrifuge is used, preferably it is proximate to one of the sides of the workstation. When two analyzers are used, preferably they are back-to-back, the back of the workstation being proximate to one of the sides of each analyzer.

In a typical analyzer, the analyzer has a base, and a pedestal sitting on the base, the pedestal having a roof. Preferably the analyzer robotic arm is on top of the roof so that it is out of the way when it is in a rest position. There can be a robotic path along the roof, and a drive for moving the robotic arm along the path, the robotic arm having a track engaging element. An extension arm can extend from the track engaging element in the same direction the path extends, with container grippers being connected to the extension arm. Preferably the extension arm is sufficiently long that when the track engaging element is at the end of the path, the robotic arm does not obstruct the top of the base of the front work area of the pedestal.

Preferably the grippers of the analyzer robotic arm are adapted for engaging container holders for lifting and transporting the holders between the analyzer receiving site and the analyzer. The holders can be sectors having a spaced pair of gripper openings in an upwardly facing wall portion thereof, the grippers having oppositely extending hook extremities for engaging a bottom surface of the wall portion through respective ones of the gripper openings. In a preferred alternative, the holders have an upstanding handle portion including a resilient member and having a cylindrical shape for facilitating effective gripping by the grippers over a range of vertical positions of the grippers relative to the holders. As used herein, "cylindrical" means having a surface that is generated by a straight line that moves parallel to a reference axis.

Transport System

The transport system (i) transports containers to and from the centrifuge receptacles, the analyzers and the decapper system; (ii) transports receptacles to and from the balance system and the centrifugation system; and (iii) transports containers in the sorting system. The transport system has a controller in communication with the central controller so the central controller can direct the transport system.

In a preferred system, the transport system includes at least two robotic arms. Each analyzer has a robotic arm for transporting the containers to and from the analyzer, and the workstation has a robotic arm for the other transport functions.

Preferably the workstation robotic arm comprises (i) a longitudinal track on the workstation, (ii) a base carriage positionable along the workstation track, the track extending proximately between opposite ends of the workstation and approximately centered laterally, (iii) a panning head controllably rotatably supported, (iv) an upper arm controllably rotatably supported on the panning head, (v) a lower arm controllably rotatably supported on an extremity of the upper arm, (vi) a wrist head controllably rotatably supported on an extremity of the lower arm, and (vii) a gripper head controllably rotatably supported therefrom on a gripper axis. The gripper head has a pair of gripper fingers extending therefrom, being controllably movable with tactile feedback toward and away from opposite sides of the gripper axis for selectively grasping and transporting containers, and holders thereof. Preferably the gripper head also includes an optical head sensor for sensing objects located proximate the gripper fingers. The head sensor can include a light source portion and a light receiver portion, and having respective source and receiver axes converging proximate the gripper axis, preferably in approximate orthogonal relation to the gripper fingers relative to the gripper axis for sensing entry of a container portion or holder extremity between the gripper fingers.

Preferably the robotic arm is provided with an indicia scanner for reading indicia of the containers and of holders of the containers, for identification of same. The indicia scanner is operative relative to a scan axis thereof, the scanner being preferably mounted to the upper arm of the robotic arm with the scan axis oriented downwardly and outwardly from proximate an upper portion of the pan head for reading indicia being both horizontally and vertically oriented when the gripper fingers are near the indicia.

Preferably the pan head is movable about the pan axis throughout an angle of greater than 180°, and the base carriage is movable to proximate opposite ends of the work station for facilitating transport of containers and holders substantially anywhere on the workstation. Further, the gripper head is preferably locatable in overhanging relation to the workstation for accessing an external process station.

It is desirable that the central controller track containers by the holders in which they are located. Accordingly, preferably the indicia reader can read the holder identification indicia, the reader output element providing holder identification indicia to the central controller for tracking containers according to the respective holders.

In other aspects of the invention, a centrifuge system includes the plurality of receptacles; the centrifuge having the spindle, centrifuge controller that indexes the spindle for automatic loading and unloading of the receptacles, and the powered lid; the balance system; and the transport system for transporting the containers and the receptacles between the balance system and the centrifuge.

A preferred balance system for the centrifuge receptacles comprises the above-identified balance system wherein the locations of containers in receptacles are correlated with weights thereof for symmetrical loading of each receptacle.

A preferred decapper according to the present invention comprises the above-identified decapper systems, including the capability of unscrewing the caps.

Test tubes containing specimens to be analyzed come in different heights and different diameters. Accordingly, the holders and centrifuge receptacles are preferably provided with spring fingers.

During use of the workstation, it is possible that the workstation becomes misaligned with the analyzer so that the analyzer robotic arm does not adequately grip holders containing containers for analysis, and/or improperly delivers holders containing analyzed specimens to the workstation. Accordingly, preferably the sites at which holders are maintained by the workstation for delivery to the analyzer or for receipt by the analyzer are provided with an adjustment mechanism for independently aligning the sites, without moving either the analyzer or the workstation. The adjustment mechanism includes a rotatable and translatable platform having at least one holder site thereon,

and a clamp activator for selectively holding the platform in a fixed position on the workstation.

Method of Using the System

A method according to the present invention makes uses of this system. In the method of the present invention, instructions for the processing of each container according to the container identification indicia are stored in the memory of the central controller. The presence of a holder in the system is detected and signaled to the central controller. Container identification indicia are read and also signaled to the central controller. The containers are transported with the robotic arm to a plurality of sort sites according to the processing instructions that are in the memory storage. Selected specimens are sorted, and optionally centrifuged, decapped, and analyzed.

For centrifugation of selected specimens, containers containing the selected specimens are transported to the centrifuge receptacles and loaded into a selected receptacle with the workstation robotic arm according to processing instructions. The loaded receptacles are then balanced, such as by loading pairs of the receptacles using symmetrical loading patterns having equal numbers of loaded positions, and/or putting in "dummy" test tubes in the receptacles that need extra weight. The balanced receptacles are placed in the centrifuge, and containers are centrifuged for a time and rate according to instructions from the central controller. The centrifuge is unloaded by stopping the centrifuge, indexing the centrifuge to selected unloading positions, and removing the receptacles from the centrifuge with the robotic arm in response to signals from the central controller.

In the analysis operation, each analyzer provides analyzer availability information to the central controller, and the central controller determines which analyzer each specimen that is to undergo analysis is analyzed by.

Accordingly, in the system and method of the present invention, sample preparation for analysis of specimens is automated. Moreover, the system can be used with existing equipment, i.e., existing analyzers can be utilized by retrofitting them with a robotic arm and data communication with a central controller. Moreover, the system can recognize and expeditiously handle STAT samples. Further, the system minimizes human handling of specimens. This reduces health risks associated with contacting biological samples and the risk of contaminating specimens.

DRAWINGS

These and other features, aspects and advantages of the present invention will become better understood from the following description, appended claims, and accompanying drawings where:

Figure 1 is a perspective view of a system according to the present invention, comprising a workstation, a centrifuge, and two analyzers;

Figures 2A-2C are flow charts of the steps of processing containers using the system of Fig. 1, Fig. 2A being for a process supervisor; Fig. 2B being for a centrifugation subsystem of the supervisor of Fig. 2A; and Fig. 2C being for an analysis subsystem of the supervisor of Fig. 2A;

Figure 2D schematically shows how the process controller of the system of Fig. 2A controls the workstation, analyzer, and centrifuge;

Figures 3A-3E are plan views of different layouts of a workstation, analyzers, and a centrifuge;

Figure 3F is a plan view of a workstation and centrifuge according to the present invention, being used with a conveyor system;

Figure 3G is a plan view of an analyzer according to the present invention being used with a conveyor system;

Figure 4 is a schematic plan view of the workstation of Fig. 1;

Figure 5 is a view of the workstation of Fig. 1, similar to that of Fig. 4, showing the location of positioning pins used for locating holders, and the location of detectors for detecting holders;

Figures 6A-6C show different types of positioning pins used with the workstation of Fig. 5;

Figure 7 is a partial sectional view of the workstation of Fig. 5, showing a detector for detecting the presence of a holder;

Figure 8A is a perspective view of a sector for use with the system, and showing how positioning pins of the workstation interface with the sector;

Figures 8B and 8C are top and bottom plan views of the sector of Fig. 8A;

Figure 8D is a partial perspective view showing an alternative configuration of the sector of Fig. 8A;

Figures 9A and 9B are a top plan view and a side elevation view, respectively of a rack for use in the system of the present invention;

Figures 9C and 9D are exploded perspective and fragmentary side sectional views of an insert portion of the rack of figs. 9A and 9B;

Figure 10A is a top plan view of a bucket seated in a spindle head cradle of the centrifuge of the system of the present invention;

Figure 10B is a side elevational view of the bucket of Fig. 10A;

Figure 10C is a bottom elevational perspective view of the bucket of Fig. 10A, and showing an alternative configuration of the centrifuge cradle;

Figures 11A-11D show different loading patterns for the centrifuge buckets according to the present invention;

Figure 12A is a top plan view of a delivery site adjustment mechanism of the workstation of Fig. 1;

Figure 12B is a sectional view of the adjustment mechanism, taken on line 12B-12B of Fig. 12A;

Figures 13A-13D show details of the robotic arm of the workstation of Fig. 1, Fig. 13A being a perspective view; Fig. 13B being a schematic plan view showing a range of movement of the robotic arm relative to the workstation of Fig. 1; Fig. 13C being a perspective view, partly exploded, of a gripper head and an optical head sensor of the robotic arm; and Fig. 13D being a perspective view as in Fig. 13C, showing an alternative configuration of the optical sensor;

Figures 14A and 14B are front and side elevational views of one of the analyzers of the system of Fig. 1, Fig. 14B being taken on line 14B-14B in Fig. 14A;

Figures 15A-15G show details of a gripper portion of the robotic arm of the analyzer of Fig. 14A, Figures 15A and 15B being front and right side elevational views; Figure 15C being a right side view as in Fig. 15B, with the gripper portion lowered into engagement with a sector; Figs. 15D and 15E being sectional views on line 15D-15D of Fig. 15A, Fig. 15E showing engagement with a sector; and Fig. 15G is a perspective view showing an alternative configuration of the gripper portion;

Figure 16A is a fragmentary front elevational perspective view of a centrifuge unit of the system of Fig. 1;

Figure 16B is a fragmentary detail rear perspective view showing an alternative configuration of an access door portion of the centrifuge unit of Fig. 16A;

Figure 16C is a detail perspective elevational view showing a drive mechanism for the access door of Fig. 16B;

Figures 16D and 16E are a pictorial block diagram and a circuit block diagram of the centrifuge unit of Fig. 16B;

Figure 16F is a simplified circuit diagram of a circuit interface module of the centrifuge unit of Fig. 16B;

Figure 16G is a flow chart for a computer program of the centrifuge unit of Fig. 16B;

Figures 17A and 17B are a top plan view and a side elevational view, respectively, of the balance subsystem of the system of Fig. 1;

Figure 18A is a perspective view of the decapper subsystem of the system of Fig. 1;

Figure 18B is a schematic view showing the decapper system of Fig. 18A on the workstation;

Figure 18C is a perspective view showing an alternative configuration of a portion of the decapper system of Fig. 18A;

Figures 18D and 18E are side sectional elevational and bottom views of the decapper system portion of Fig. 18C;

Figure 18F is a fragmentary side elevational view of an alternative receiver portion of the decapper system portion of Fig. 18A

Figure 19 is a diagram of a pneumatic subsystem of the system of Fig. 1;

Figures 20A and 20B are exploded perspective and side elevational views of a workstation table of the system of Fig. 1; and

Figure 21 is a fragmentary sectional elevational view of a door portion of a protective shield of the workstation.

DESCRIPTION

System Overview

With reference to Figs. 1, 2, 4, 8A, 9A, and 10A, a system **10** according to the present invention comprises, as its main components, a workstation **100**, a centrifuge unit **1000**, and at least one analyzer **2000**, and typically two analyzers, designated **2000A** and **2000B**. The workstation **100** is loaded with containers **12**, such as test tubes **102** (see Fig. 8A) by an operator. The test tube **102** is provided with identification indicia, namely a bar code **104** and a cap **103**. Typically the containers are held in a holder **14**, such as a sector **300** (Fig. 8A) or a test tube rack **600** (Fig. 9A). For centrifugation, the containers **12** are typically transferred to receptacles or buckets **1200** (Fig. 10A).

As shown in Fig. 2A, a process supervisor **200** of the system **10** includes a detect input step **202** for detecting presence of containers **12** at an input location **16** (Fig. 4) of the workstation **100**. In a container select step **204**, detected containers **12** are then selected for processing. Processing is on a first-in, first-out basis, except for containers that need priority or "STAT" treatment. Those containers **12** are placed by the operator within a priority region **18** on the workstation **100** for priority processing.

After a container **12** is selected for processing, the container ID, i.e., the bar code **104**, is read in a container ID read step **206**, and main process components are defined in a process select step **208**, based on processing specified for the container **12**. The container is then processed in one or more of a centrifugation step **210**, a decapping step **212**, an analysis step **214**, and an output sorting step **216**.

For a specimen that is to undergo complete processing, the container is sent by the centrifugation step **210** to the centrifugation subsystem for centrifuging in the centrifuge unit **1000** (Figs. 16A-16G). The centrifuged container is then processed in the decapping step **212** by a decapping subsystem **900** (Figs. 18A and 18B). Decapped samples are then transported in the analysis step **214** for analysis on any available analyzer. Substantially any type of analysis that is effective for biological materials can be done, including analysis of urine, blood, and cerebrospinal fluid. Moreover, the system **10** of the present invention can be used for industrial analysis, and thus is not limited to biological substances.

After analysis on one or both analyzers **2000**, the containers are returned to the workstation **100**, and then subjected to output sorting in the output sorting step **216**, wherein each container **12** is put into a specified holder **14**. Some of the holders **14** are for containers that will undergo further analysis or processing; other holders being for containers whose processing is completed.

As further shown by Fig. 2A, containers **12** need not go through all of the processing steps **210**, **212**, **214**, and **216**. For example, the workstation **100** can be used just for output sorting. Alternatively, it can be used for containers that do not need centrifugation and/or decapping, the supervisor **200** using the results of the process select step **208** for determining subsequent ones of the processing steps. For example, appropriate ones of the containers **12** can be sent straight to analysis and then output sorting.

The centrifuge unit **1000**, which is described in detail below, is designed for centrifuging containers that are loaded in receptacles or buckets **1200** (Fig. 10A). Each bucket **1200** holds multiple containers to be centrifuged, and the centrifuge **1000** is adapted for centrifuging multiple buckets **1200**, typically four. It is important for the proper operation of the centrifuge and to avoid damage to the centrifuge, that buckets loaded across from each other in the centrifuge have substantially the same weight, within typically about 10 grams.

The centrifugation step **210** supervises the centrifugation subsystem generally as shown in Fig. 2B. In the centrifugation subsystem, the buckets **1200** are loaded in selected locations, and the location for each container in each bucket is stored in memory. The buckets are loaded in a predetermined order to be approximately balanced as well as reasonably permitted by the specific complement of containers **12** requiring centrifugation. Preferably the loading is monitored by a balance system **800** (Figs. 17A, 17B) and the buckets **1200** are further balanced to comply with a predetermined tolerance. The balanced buckets are then loaded into the centrifuge **1000**, centrifuged, and then unloaded. The individual containers **12** are then unloaded from the buckets **1200** for further processing.

The analysis step **214** supervises the analysis subsystem generally as shown in Fig. 2C, the containers **12** (typically the test tubes **102**) being placed in sectors

300, and data corresponding to the particular sector in which the container is located is stored in the memory of a process controller 500. As shown in Fig. 1, a loaded sector 300 is placed at a delivery site 106 of the workstation 100 by a robotic arm 700 of the workstation 100, there being a delivery site 106 for each of the analyzers. An analyzer robotic arm 2002 picks up the sector from the delivery site 106 and delivers it to an analyzer transfer site 2004. The analyzer 2000 then proceeds to analyze the specimen according to processing instructions from the process controller, and stores the results of the analysis in the memory of the process controller 500. Then the analyzer robotic arm 2002 picks up the sector 300 containing analyzed specimens from the analyzer transfer site 2004 and returns them to a workstation receiving site 110. The sector 300 at the workstation receiving site 110 is then picked up by the workstation robotic arm 700 for sorting.

Fig. 2D shows the data and operating instruction information flow between the various components of the system 10. The system includes the central process controller 500, which can be typically a computer system. Exemplary of the computer systems that can be used are industrial counterparts of commonly available 32-bit personal computers having read-write memory in the several megabyte range. The controller 500 is provided a suitable input device such as a keyboard, touch screen, card reader, or another computer, for inputting processing instructions into memory for processing each of the containers 12 according to container identification indicia.

The process controller 500 provides instructions for mechanical control of the workstation 100, using feedback in the form of station status and sample identification data. The analyzers 2000 are provided with respective controllers 2008A and 2008B as well as a separate controllers 2010A and 2010B for the robotic arms 2002. The analyzer controllers 2008A and 2008B can be commercially available industrial microcomputers, or counterparts of the process controller 500. Each of the analyzer controllers 2008A and 2008B has an output interface for providing the central controller 500 information from each analyzer about availability, whether the analyzer can perform a particular test, and test results. In return, the process controller 500 provides test requests to each analyzer 2000 for each specimen, as well as operating instructions through an input interface of the corresponding controller 2008A or 2008B. Similarly, the process controller 500 provides to each of the analyzer robotic arm controllers 2010A and 2010B various load and unload instructions. Suitable devices for

the analyzer robotic arm controllers **2010A** and **2010B** are available from a variety of industrial robot suppliers.

Based on the analyzer availability information provided by each analyzer output to the central controller **500**, the central controller selectively determines which analyzer to use for each specimen. This can be effected by software loaded in the controller memory, where the software compares analyzer availability data against the tests required by the specimen. The analyzer availability data includes what tests each analyzer is capable of performing, and analyzer status information, such as whether reagents are loaded for particular tests and analyzer backlog.

The process controller **500** also provides mechanical control instructions to the centrifuge unit **1000**, and receives status information from the centrifuge unit.

Optionally, the entire system can be interfaced with a host computer **502**. The host computer **502** can be interfaced with multiple systems, each system containing a workstation, a centrifuge, and one or more analyzers. The host computer can be used for inputting instructions for each specimen to the process controller **500**, and the test results can be reported by the central process controller **500** to the host computer **502**.

The interfaces between the components of the system, i.e., output elements, output system elements, and input system, can be conventional data connections, such as RS 232 connectors with interconnecting cables, buses, and data transport mechanisms such as IR transfer or direct hard wiring.

Layout of System Components

As shown in Fig. 1, the workstation **100** comprises a table **112** having a table top **114**. The workstation has a front or input section **116**, a rear or analyzer section **118**, and two opposed sides **120**. The front has placement locations for placement of holders **14** for holding containers **12** that are to be processed, containers whose processing has been completed, and containers which have been partially processed. Down the middle of the table is a track **704** for the robotic arm **700**.

The system is adapted to be used with many configurations of holders **14**. For example, it can be used for sectors **300** as shown in Figs. 8A, 8B, and 8C, which hold a small number of test tubes **102**. Sectors **300** are particularly useful for containers which need to undergo identical processing. As detailed below, the workstation robotic

arm **700** has grippers **726** adapted to grip not only individual containers **12** but also the sectors **300**, so that a group of containers **12** can be transported for various processing steps simultaneously. The workstation **100** can also be used with racks **600**, as shown in Fig. 9, which are capable of holding multiple containers. The containers **12**, which typically are test tubes **102**, are removed one by one from the rack **600** for processing. Preferably the racks **600** are placed closer to the robotic arm track **704** than the sectors **300**, to help speed up and increase the throughput of the system. On the analyzer section **118** of the workstation **100**, there are located sectors **300** containing containers for delivery to and to be received from the analyzers **2000**.

As shown in Fig. 1, the workstation robotic arm **700** is preferably centrally located on the table **112** for easy access both to the front input section **116** and the analyzer section **118** of the table. Also, the centrifuge **1000** is preferably positioned at one of the sides **120** of the workstation **100**, for permitting operator access to the full length of the front or input section **116** of the table **112**, the rear or analyzer section **118** being reserved for access by the analyzers **2000**.

In the layout of Fig. 1, the analyzers **2000** are positioned with their sides proximate to, and preferably abutting, the workstation **100**, with the two analyzers **2000** being back-to-back. In the configuration of Fig. 1, the workstation **100** does not interfere with operation of either analyzer, and neither analyzer interferes with operation of the workstation. Moreover, the centrifuge **1000**, being located at one of the ends of the workstation, is likewise out of the way of the analyzers and the workstation. The analyzers are substantially identical, differing in that one (**2000A**) is "right armed" with its robotic arm **2002A** positioned to reach to the right to the workstation **100**, and second analyzer **2000B** is "left armed" with its robotic arm **2002B** positioned to reach to the left to the workstation **100**.

Figure 3A is a top plan view of the layout of the system shown in Fig. 1. Alternative layouts are possible, such as shown in Figs. 3B-3F. The layout of Fig. 3B is the same as that of Fig. 3A, except that the centrifuge **1000** is placed in a U-shaped space formed by the workstation **100** and the two analyzers **2000**, up against the back **2020** of the base **2012** of both workstations.

In the version of the invention shown in Fig. 3C, the layout is the same as that shown in Fig. 3B, except that the second analyzer **2000B** is placed against the end of the workstation **100** that is distal from the first analyzer.

In the layout of Fig. 3D, the two analyzers **2000** are placed on opposite sides of the workstation **100**, thereby forming a "cross," with the right hand analyzer **2000A** up against the rear **118** of the workstation and the left hand analyzer **2000B** against the front **116** of the workstation **100**. The centrifuge **1000** is at one of the ends of the workstation, as in the layout of Fig. 3A.

The layout of Fig. 3E is similar to that of Fig. 3D, except the two analyzers **2000** are positioned at the centrifuge end of the workstation **100** rather than in the middle of the workstation. The layout of Fig. 3E is advantageous compared to that of Fig. 3D in that the workstation input side is not obstructed by either analyzer.

As is evident from these various layouts, it is possible to position the workstation and centrifuge **1000** so that they do not obstruct access to either analyzer.

The workstation and centrifuge of the present invention are not limited to use in direct conjunction with analyzers as shown in Figs. 3A-3E. Instead they can be used with the conveyor system that includes a conveyor **126**, as shown in Figs. 3F and 3G. In the version of Fig. 3E, the robotic arm **700** of the workstation picks up containers, generally in sectors, from the conveyor **126**, processes the containers, and optionally the containers are centrifuged. Then processed containers are returned to the conveyor **126**.

In the version of Fig. 3G the conveyor cooperates with the analyzer **2000** whose robotic arm **2002** picks up and delivers containers, and/or sectors, to the conveyor **126**.

Analyzers

The analyzers **2000** shown in Fig. 1 are Synchron CX analyzer units available from Beckman Instruments of Fullerton, California, being modified or retrofitted to incorporate the robotic arms **2002** as described herein. As also shown in Figs. 14A and 14B, each analyzer **2000** has a base **2012** having opposed sides **2014**, a front **2016**, a top **2018** and a back **2020**. The top **2018** has the analyzer transfer site **2004** and analytical equipment thereon and is accessible from the front by a user. A pedestal

2022 is provided on the back portion of the top 2018 of the base 2012, the pedestal 2022 having a front work area 2024 and a roof 2026. On top of the roof 2026 is a transport mechanism including the robotic arm 2002, for automated transport of specimens from the workstation 100 to the analyzer 2000, and for transport of the analyzed specimens from the analyzer 2000 to the workstation 100. A path or track 2028 having a drive 2030 therein extends across the roof 2026 for moving the robotic arm 2002 along the path 2028. The robotic arm 2002 has a track engaging element 2032, and an extension arm 2034 extending from the track engaging element 2032 in the same direction the path 2028 extends. From the end of the extension arm 2034, there is a forwardly extending arm 2036, with a downwardly depending arm 2038 at the end of the forwardly extending arm 2036. At the bottom of the forwardly extending arm are grippers 2040.

Because of the extension arm 2034, the grippers 2040 can reach sectors 300 on top of the workbench 100. Moreover, in a "rest" position, the robotic arm 2002A of the first analyzer 2000A is out of the way with regard to the top 2018 of the base 2012 and the front work area of the pedestal, and thereby does not interfere with processing and operator access to the analyzers.

As further shown in Figs. 15A-15F the grippers 2040 of each analyzer robotic arm 2002 are supported from a gripper actuator 2041, the actuator 2041 being mounted on a bracket 2042 that is rigidly attached to an elevator member 2043 of the robotic arm 2002. A crank member 2044 is movable about a vertical axis 2045 of the actuator 2041 between first and second positions through an angle of approximately 180° for selective opposite orientational placement and recovery of sectors 300 at the analyzer transfer site 2004 and at the workstation delivery site 106. A robotic clamp 2046 is mounted to an end extremity of the crank member 2044 for movably supporting an outwardly facing pair of hook-shaped gripper members 2048, each of the gripper members 2048 being insertable through a respective top wall slot 322 of the sector 300, the sectors 300 being described below in connection with Figs. 8A-8C. After such insertion, hook-shaped end extremities 2049 of the gripper members 2048 engage the underside of a top wall 306 (having the slots 322 formed therein) upon activation of the clamp 2046 for separating the gripper members 2048. Also, each gripper member 2046 has an extractor member 2050 vertically slidably engaged therewith, a vertically oriented

compression spring **2052** being interposed above the extractor member for biasingly contacting the top wall **306** between the slots **322** when the gripper members **2048** extend into the slots **322**. One purpose of the extractor members **2050** is for insuring that the sector **300** remains in place undisturbed when being deposited at a site, the extractors holding the sector down during withdrawal of the gripper members **2048** during raising of the elevator member **2043**. Another purpose of the extractor members **2050** is for stabilizing the sector **300** on the gripper members **2048** during manipulation by the analyzer gripper **2040**.

A device suitable for the actuator **2042** is available as Model NCRB/BW30-180S rotary actuator, from SMC of Tustin, CA. A device suitable for use as the robotic clamp **2046** is Model HGP-10-A gripper, available from Festo, of Hauppauge, NY. Devices suitable for use as the analyzer track **2028** and drive **2030** are available as Model IS-MX-20-200-400 robotic positioning system with Model SA-A vertical moving feature, from Intelligent Actuator of Torrance, CA.

With further reference to Fig. 13G, a preferred alternative configuration of the gripper members **2048** for use with the sectors **300'** includes one gripper member, designated **2048'**, for engaging the resilient block **334**, and a complementary gripper member, designated **2048''**, for clamping against the back wall **305** of the sector **300'**.

Workstation

A layout of a preferred workstation **100** or bench is shown in Fig. 4. This layout is particularly adapted for having the centrifuge **1000** on the right side of the workstation **100** as shown in Figs. 1 and 4. On the input section **116** of the table **112**, there are provided fifteen sort sites **128** labeled from left to right, as A-O, for sectors **300**, and corresponding fifteen sort sites **130** A-O for racks for holding test tubes. The track **704** for the robotic arm **700** extends down the middle of the table, extending from end to end, dividing up the table into the input sections **116** and the analyzer section **118**. The racks are closer to the track **704** than are the sectors, because there is more travel of the robotic arm associated with the racks, where the containers need to be loaded and unloaded one by one.

In a typical assignment of the sector and rack sites, the input locations **16** include rack sites **128** and sector sites **130** labeled A-J, where new containers to be

processed are located (including the priority region **18** at site A, for "STAT" specimens); the output locations **17** include sites N and O, where sectors and racks having completed processing and awaiting removal from the workstation **100** are located; and the auxiliary region **19** include sites K-M, where sectors and racks having specimens ready for analysis are located, such as for a first analysis by one of the analyzers, or for specimens having already been analyzed by one analyzer and are ready for a second analysis process on a second analyzer. It will be understood that the particular division of functions for the locations on the input section **116** can vary depending on the throughput rates of the analyzers, the number of analyzers available, and other factors, and the assignments can differ as between the rack sites **128** and the sector sites **130**.

The racks **600**, which can be provided with a bar code identification **601**, are used for storing and/or sorting test tubes, and as a way of removing and placing large quantities of test tubes on the workstation. The sectors **300**, although having smaller capacity, can be picked up by the robotic arms **700** and **2002**, being used not only for processing but also for sorting multiple test tubes simultaneously, thereby adding to the efficiency of the workstation **100**.

The workbench of Fig. 4 is adapted for use with at least two analyzers. Thus, a "launch pad" **105** at each end of the analyzer section **118** has the delivery site **106** for pickup of sectors by the analyzer robotic arm **2002**, and the receiving site **110** for delivery of sectors containing analyzed samples from the robotic arm **2002**. Surrounding the launch pads are a plurality of sector locations **134** being used for empty sectors, or for locating loaded sectors at peak processing times when the input section is full.

In the middle of the analyzer side are buckets or receptacles **1200**, and a scale **802** and an auxiliary rack site **804** of the balance system **800**. Figure 4 shows four buckets or receptacles **1200** on the scale **802** for balancing, the auxiliary site **804** having a rack **600** for dummy test tubes **806** that are used for balancing out the weight of the loaded buckets. To the right of the auxiliary rack site **804** is the decapping system **900**, followed by four buckets **1200** either being unloaded after centrifuging, or being loaded with new test tubes for centrifuging.

With further reference to Figs. 20A and 20B, a preferred configuration of the table **112** includes a base **20** having a parallel-spaced pair of beam members **22** that connect a spaced plurality of bulkheads **24**, the bulkheads **24** having respective column

portions **25** that support a rail member **26**.of the track **704**. Each of the bulkheads **24** also anchors a pair of column members **28** on the beam members **22** the input and analyzer sections **116** and **118** of the table **114** being separately fastened on top of respective rows of the column members **28**. By this construction, the table **112** can be conveniently stored and transported as one compact package including the beam members **22**, the rail member **26**, and the sections **116** and **118**, and another compact package including the bulkheads **24** having the column members **28** fastened thereto. There are five of the bulkheads **24**, the spaces therebetween defining four bays for accommodating various power distribution and electronic components of the system **10** in a conventional manner. Under each end bulkhead **24** is mounted a pair of swivel casters **130** for rollably supporting the workstation **100**, and an adjustable foot assembly **132** is spaced inwardly from each end and mounted under each beam member **22** for leveling and anchoring the table **112** in a conventional manner.

A typical workstation has a length of about 2.83 meters, and an overall width of about 980 mm, with the input section being about 540 mm wide, a track width of about 145 mm, and the analytical section being about 440 mm side.

As further shown in Fig. 1, the workstation **100** is preferably provided with a protective shield system **40** for blocking operator intrusion within space above the table top **114**. The shield system **40** has a frame **42** on which are mounted a plurality of transparent panel members **44**, being vertically oriented proximate the perimeter of the table top **114**, the shield system **40** being interrupted along the rear section **118** for clearing the respective analyzer robotic arms **2002A** and **2002B**. The panel member proximate the centrifuge unit **1000**, designated **44A**, has a bubble extension **46** formed therein for inclusion of a path to the centrifuge unit **1000** within the shield system **40**. Also, and with further reference to Fig. 21, the panel member along the front section **116**, designated **44B**, extends down only partway from the top of the frame **42**, three transparent door panels **48** being supported for vertical movement in overlapping relation with respective portions of the panel **44B**. Each of the door panels **48** is coupled to a piston rod **50** of a pneumatic actuator **52** by a handle clamp assembly **54**, the actuator **52** being mounted to a top portion of the frame **42**. A solenoid latch **56** is located within the table **114** in association with each door panel **48** for locking same in a closed position thereof. In an exemplary configuration as shown in Fig. 21, the solenoid latches **56** when deactivated engage discontinuities or slots **58** that are formed in lower

extremities of the piston rods **50**; activation of the latches **56** releases the rods **50**. The door panels **48** are reinforced against excessive inward force by the handle clamp assemblies **54** having depending projections **60** thereon that extend proximately against an edge extremity of the table top **114** in the closed positions of the panels **48**. A door button **62** is located under each handle clamp assembly **54** for signaling an associated door open request to the process controller **500**. Subject to appropriate interlocks and process suspension, the corresponding latch **58** is activated, followed by activation of the corresponding pneumatic actuator **52**, whereupon the door panel **48** is raised for operator access to the input section **116** of the workstation **100**. The workstation **100** is preferably provided with two emergency stops **64**, one proximate each end of the input section **116**, for use by an operator.

With reference to Fig. 5, there are provided two sector registration posts or pins **142** for each sector **300**. Similarly, two rack positioning pins **146** are provided for locating each rack **600** that is on the workstation **100**. A table magnet **145** is mounted flush with the table top **114** in predetermined relationship with pairs of the pins **142** and **146** for attracting respective holder magnets **330** of the sectors **300** and the racks **600** as further described below. Also, there are two bucket locator pins **144** on the workstation **100** for each receptacle or bucket **1200** used for the centrifuge. Figs. 6A-6C show a typical sector pin **142**, rack pin **146**, and bucket pin **144**, respectively. The particular shape of the pins is selected so they cooperate with the respective devices they serve to locate. As shown in these figures, the three types of pins are different, to inhibit operators from mislocating the devices on the workstation. As further shown in Figs. 6A-6C, the pins **142**, **144**, and **146** on the table **114** are located in shallow wells **156** for confining any inadvertent spillage from the containers **12**. Counterparts of the wells **156** are also provided on the scale **802**. Further, a perimeter trough **158** is formed in each of the front and rear sections **116** and **118** of the table **114** and surrounding the various sites for the holders **14**, as shown in Fig. 6A.

The cooperation between the sector pin **142** and a sector **300** is shown in Fig. 8A; the cooperation between the rack a **600** and the rack locating pins **144** is shown in Figs. 9A and 9B, and the relationship between a centrifuge bucket **1200** and the bucket location pins **146** is shown in Fig. 10C, which shows the pins **146** in an alternative configuration of the centrifuge **1000**.

The workstation is provided with a detection system for detecting the presence of sectors and racks on the workstation. In a preferred version of the invention shown in Fig. 7, there is used a sensor or reed switch **150**, which is recessed slightly below the top surface of the workstation. Each reed switch **150** is retained by a flush-fitting plug member **152** that is removable for facilitating servicing and/or replacement of the reed switch **150**. Preferably, electrical circuits of the reed switches **150** are provided with suitable connectors (not shown) for facilitating replacement of the switches **150** without requiring access below the table top **114**. The locations of the reed switches **150** are shown in Fig. 5. The reed switches can be activated by providing the sectors, racks, and buckets with magnets strong enough to activate the reed switch. Also, other detection systems can be used, including weight systems where the detector detects the presence of a sector or the like by its weight; or a detector system that relies on an electrical current, where the presence of a sector or rack closes a circuit so electrical current can be detected; or an optical interrupter, where the device interrupts a light path.

An exemplary sector **300** as shown in Figs. 8A, 8B, and 8C includes a base **301** having a convex front wall **302**, a concave back wall **304**, a bottom wall **308**, and side walls **310**. A top **315** snap fits onto the base **301** and includes a a top wall **306** that extends rearwardly and outwardly from portions of the side walls **310** of the base (the side walls **310** being staggered for clearing the sector positioning pins **142** of the workstation **100**, thereby forming an overhang **318**, which has two holes **320** therein for the pins **142**. Along the front wall **302** are tubular cavities **314** for test tubes **102**, and in the version shown in the figures, there are seven such cavities. They extend from the top wall **306** and can drain through the bottom wall **308**. Each cavity **314** has a slot **316** in the front so that a bar code reader can read the bar codes **104** on the front of the test tube **102**. In the top wall **306** are two slots **322** which can be engaged by the gripper members or jaws **2048** of the analyzer robotic arm **2002** (Figs. 15A-15F). The slots **316** extend partially in the base **301** and partially in the top **315**.

Extending upwardly from the top wall **306** of the sector **300** is a counterpart of the back wall, designated **305**, from which projects a T-shaped handle **324**, the combination of the back wall **305** and the handle **324** being engageable by the gripper element **726** of the workstation robotic arm **700** (Fig. 13C).

The front wall **302** of the sector **300** is provided with a bar code **326** to identify, and allow the central controller **500** to track the sector and the test tubes therein. The base **301** is also provided with an internal bar code strip **327** which is visible when a test tube slot **316** is empty, but blocked when a test tube is in the slot. Thus a bar code scanner **724** (Fig. 13A) can signal the central processor **500** with the number and location of test tubes in each sector. A holder magnet **330** is mounted flush with the bottom wall **308** for stabilizing the sector **300** and holding the sector in place on the workstation **100** during removal of test tubes **102**. The holder magnet **330** is located and oriented for attraction by respective ones of the table magnets **145** of the workstation **100**. A sensor magnet **332** is likewise mounted flush with the bottom wall **308**, for activation of respective reed switch sensors **150** of the workstation **100**.

With further reference to Fig. 8D, an alternative and preferred configuration of the sector, designated **300'**, has the back wall **305** (and the handle **324**) extended somewhat from the top wall **306** and having a rearwardly projecting lip portion **305'**, a triangularly shaped resilient block **334** being retained on the handle **324** proximately against the underside of the lip portion **305'**. The resilient block **334** advantageously facilitates reliable engagement of the sector **300'** by the gripper members **2048'** and **2048"** of the analyser robotic arms **2002** in the configuration of Fig. 13G, by permitting increased vertical (and horizontal) alignment tolerance as compared with the engagement configuration of Fig. 15E. The resilient block **334** also facilitates more effective gripping by the gripper members **726** of the workstation robotic arm **700** in the configuration of Fig. 13D, by resilient conformity of the block **334** with one of the gripper members **726**, and by the combination of the block **334** and the back wall **305** having a non-circularly cylindrical shape, the engagement producing a centered and vertically aligned relationship between the sector **300'** and the gripper axis **715** regardless of slight variations in vertical positioning of the gripper members.

Because laboratories typically process specimens from different sources, such as different hospitals, testing labs, and doctors' offices, the containers or test tubes **102** often have different diameters and different heights. To accommodate variations in diameters, the top **315** has four depending fingers **328** for each test tube slot **314**, the fingers being biased radially inwardly. The sector **300'** shown in the Figure 8D is available from Beckman Instruments with the Synchron CX machine.

With reference to Figs. 9A-9D, a test tube rack **600** suitable for use in the system **10** includes a frame **602** having the bar code identifier **601** applied thereto, and defining a 5 by 10 array of vertical cavities **603**. The frame includes holes **604** for the positioning pins **146**, and has counterparts of the holder and sensor magnets **330** and **332**. Each of the cavities **603** is provided with an insert member **606** having spring fingers **607** to hold different size test tubes in the rack, the fingers being formed for retaining a resilient O-ring member **609** that augments frictional engagement of containers **12** being test tubes **102** by the fingers **607**. Thus each rack **600** forms a holder **14** for the containers **12**, the cavities **603** being typically spaced at a pitch of approximately 20 mm, the inserts **606** being sized for biasingly centering the containers **12** up to approximately 16 mm in diameter, the combination of the finger members **607** and the O-ring **609** being sufficiently resilient for effectively centering containers not larger than approximately 13 mm in diameter.

Although the present invention is described with regard to bar code and bar code readers for tracking test tubes and other components of the system, other detection systems can be used. For example, magnetic ink labels can be placed on test tubes and other components, to be read by a magnetic ink reader.

With reference to Figs. 10A, 10B and 10C, the buckets or receptacles **1200** each have an array of cavities **1203** corresponding to the openings **603** of the racks **600**, the cavities **1203** symmetrically surrounding a stem member **1204**. An upper portion of the stem member **1204** is square in cross-section for engagement by the gripper members **726** (Fig. 13C) of the robotic arm **700** in any of four discrete orthogonal orientations, a spaced pair of resilient O-rings **1206** being retained on the stem member for augmenting frictional engagement by the gripper members **726**. As shown in Fig. 10A, there are 16 of the cavities **1203** in each receptacle **1200**, each cavity **1203** being defined by a counterpart of the insert **606** and having counterparts of the finger members **607**. The receptacles **1200** are adapted for placement in respective cradles **1008** of the centrifuge unit **1000**, having a pair of notches **1208** formed in opposite sides thereof for registration with respective bearing caps **1009** of each cradle **1008** as shown in Fig. 10A.

As shown in Fig. 10C, each receptacle **1200** is formed with a pair of holes **1210** for registration on corresponding bucket positioning pins **144**, and a counterpart of

the sensor magnet **330** for activation of the associated reed switch sensor **150** of the workstation table **114** (Fig. 5). Optionally and a further shown in Fig. 10C, a counterpart of the sensor **150** can be located in or under the cradle **1008** for sensing a seated condition of the receptacle **1200** in the centrifuge head **1006**, and/or counterparts of the positioning pins **144** can be mounted on the cradle **1008** as an alternative to registration of the receptacle **1200** by the bearing caps **1009**.

When loading buckets with test tubes for use in the centrifuge, it is important they be loaded in a systematic way to provide balance. Figures 11A-11D provide a top plan view of receptacles **1200** loaded into the centrifuge, showing satisfactory loading patterns. Empty test tube cavities **1203** are represented by unfilled circles, blackened circles representing cavities loaded with test tubes **102**. The buckets are loaded to provide even weight on opposite sides of the center point of the centrifuge, as well as maintain each receptacle approximately balanced relative to the respective stem member **1004**. Other suitable loading patterns are known to those of ordinary skill in the art.

With particular reference to Figs. 13A, 13B, and 13C, an exemplary configuration of the robotic arm **700** includes a base carriage **702** that is positionable along the workstation track **704**. The track **704** extends proximately between opposite ends of the workstation **600** approximately centered between opposite sides thereof, and having protective accordion covers **705**. A panning head **706** is controllably rotatably supported on a vertical pan axis **707** of the base carriage **702**, an upper arm **708** being likewise controllably rotatably supported on a horizontal shoulder axis **709** of the panning head **706**. A lower arm **710** is likewise controllably rotatably supported on an elbow axis **711** of the upper arm **708**, the elbow axis **711** being parallel-spaced from the shoulder axis **709** at an outer extremity of the upper arm **708**. Similarly, a wrist head **712** is controllably rotatably supported on a wrist axis **713** of the lower arm **710**, and having a gripper head **714** controllably rotatably supported therefrom on a gripper axis **715**. The axes **713** and **715** are orthogonal, the wrist axis **713** being parallel-spaced from the elbow axis **711** at an outer extremity of the lower arm **710**. The gripper head **714** has a gripper body **716**, pair of gripper armatures **717** being controllably movable with tactile feedback toward and away from opposite sides of the gripper axis **715**. The gripper head **714** also includes an optical head sensor **718** fixably supported relative to the gripper body **716**, the head sensor **718** including a light source **719** having a source

axis **720**, and a light portion **721** having a receiver axis **722**, the axes **720** and **722** converging proximate the gripper axis **715** from opposite sides thereof in spaced relation to the gripper body **716** and the gripper armatures **717**. The robotic arm **700** also includes a robot control system (not shown) having suitable provisions for manipulating the gripper head **714** relative to the workstation track **704** for grasping and transporting objects in a manner known to those having skill in robotics. As so far described, the exemplary robotic arm **700** is a commercial device, available as Model 255 from CRS Robotics of Ontario, Canada.

As further shown in the drawings, the robotic arm **700** is provided with an indicia scanner **724**, sometimes referred to herein as bar-code scanner **724**, the scanner **724** having a scan axis **725** and being fixedly located on the upper arm **708** such that the scan axis normally intersects the gripper axis **715** distally from the intersection of the source and receiver axes **720** and **722**. Thus the scanner **724** is advantageously oriented on the upper arm **708** for permitting effective scanning of both vertically and horizontally oriented indicia. Particularly, the container indicia **104** are normally vertically oriented, while the various indicia of the racks **600**, receptacles **1200**, and sectors **300** are normally horizontally oriented. Moreover, the gripper head **714** is provided with a pair of gripper members **726**, the gripper members **726** being mountable on respective ones of the gripper armatures and being adapted for grasping containers, receptacles, and sectors as described herein, for transport thereof. Further, the head sensor **718**, in combination with programmed movement of the gripper head **714**, permits determinations of the heights of the containers **12** for effective engagement by the gripper members **726**.

As further shown in Fig. 13B, the robotic arm **700** is movable about the pan axis **707** within an angle θ that is symmetrical on opposite sides of the workstation track **704** and greater than 180°, being approximately 315°. This range of angular orientations about the pan axis **707**, in combination with the base carriage being movable to proximate each end of the workstation **600**, facilitates transport of containers **12**, sectors **300**, and other holders to virtually any location within the table **114**, often without requiring movement of the base carriage **702** along the workstation track **704**. Also, the gripper head **714** is advantageously locatable in overhanging relation to the table panel **114** for accessing the centrifuge unit **1000**.

With further reference to Fig. 13D, an alternative configuration of the gripper head **714** has the head sensor **718** on one side only of the gripper body **716**, a laser source **719'** being substituted for the emitter **719** and mounted adjacent the light receiver **721**. Thus the source and receiver axes **720** and **722** converge from the same side of the gripper axis **715**; however, the laser source **719'** more than compensates for any loss of effectiveness of the sensor **718** that would be attributable to the axes **720** and **722** being asymmetrical relative to the gripper axis **715**.

Site Adjusters

The workstation delivery site **106** and receiving site preferably are provided with a site adjustment mechanism **961** for each of the analyzers **2000**, each adjustment mechanism **961** facilitating exchanges of holders **300** between the workstation **100** and the corresponding analyzer **1200**. As shown in Figs. 12A and 12B, the delivery site adjuster **961** includes a platform member **962** and a clamp member **964** that are movably coupled on opposite sides of the table panel **112** of the workstation **100** by a plurality of threaded fasteners **965**, the fasteners **965** and a boss portion **966** of the platform member **962** extending through a clearance opening **967** that is formed in the table **112**. Each of the fasteners **965** carries a compression spring **968** for biasing the platform member **962** and the clamp member **964** into clamping engagement with the table panel **112**, the platform member **962** also having an O-ring **969** partially recessed therein for frictionally gripping the table during the clamping. A pneumatic cylinder **970** is coupled between the clamp member **964** and the boss portion **966** of the platform member **962** for releasing the clamping in response to selective application of pressurized gas to a gas port **971** of the pneumatic cylinder **970** by a gas pressure system **850** (Fig. 19). Thus the platform member **962** is freely rotatable and laterally translatable while the pneumatic cylinder **970** is activated. The platform member **962** has two pairs of the locating pins **142** mounted thereon for locating and holding corresponding sectors **300** thereon, the sectors **300** being accessible by either the workstation robotic arm **700** or the corresponding analyzer robotic arm **2002**. Also, the platform member **962** has sensors **150** imbedded therein for sensing corresponding sectors **300** being registered on the associated pair of pins **142**, each sensor **150** being typically implemented as a conventional magnetic reed switch and coupled for signalling with the process controller **500**.

Once each analyzer **2000** is set up in proximate alignment with the workstation **100**, the associated alignment mechanism **961** is adjusted by first activating the pneumatic cylinder **970** for releasing the clamping, then manually positioning and orienting the platform member **962** for alignment of the sectors **300** with the analyzer gripper **2040** in corresponding workstation transfer positions of the analyzer robotic arm **2002**. The pneumatic cylinder **970** is then released for clamping the platform member **962** in the aligned position, thereby effecting the adjustment. Finally, the position and orientation of the platform plate **962** is stored in memory of the process controller **500** by any suitable means, such as by scanning the sectors **300** in seated positions thereof on the platform member **962** using the optical head sensor **718** of the workstation robotic arm **700**.

Balance System

As indicated above, and with particular reference to Figs. 4, 17A, and 17B, the processing system **10** includes a balance system **800** for balancing containers **12** in receptacles or buckets **1200** prior to centrifugation, the balance system including the scale **802** and the auxiliary rack site **804** on the rear section **118** of the workstation **100**. The scale **802** can be a conventional electronic platform scale to which is added counterparts of the bucket positioning pins **144** for locating the receptacles **1200**. Buckets are moved between the scale **802**, the centrifuge unit **1000**, and other locations on the rear section **118** by the workstation robotic arm **700**, which also transfers containers **12** to buckets **1200** on the scale **802** from a rack **600** at the auxiliary site **804** as well as from other locations on the workstation **100**. The balance system **800** also includes a balance controller for selectively depositing containers in cavities of the receptacles while correlating incremental weight changes with the locations of each deposit for equalizing weight in pairs of the receptacles. The balance controller can be implemented as a balance program **808** within the central process controller **500**, the balance program **808** maintaining a database **810** of container locations and associated weights, and directing the robotic arm **700** for depositing the containers **12** into the receptacles **1200** in response to weights measured by the scale platform **802**, the weights being signaled in any suitable manner to the process controller **500**.

Preferably the balance system also includes a supply of dummy loads **806** (which can be test tubes **102** that are loaded with predetermined weights) to be

selectively deposited into the receptacles **1200**. Accordingly, the balance controller is operative for moving dummy loads **806** to appropriate locations in particular receptacles **1200** for limiting weight variations between receptacles. Preferably the dummy loads **806** are progressively weighted for limiting the weight variations in pairs of the receptacles **1200** to not greater than 10 grams. The auxiliary rack site **804** is provided on the workstation **100** proximate the scale **802** for facilitating temporary storage of the dummy loads **806**, the rack **600** at the site **804** also providing additional temporary storage for containers **12** to be further processed and/or sorted.

In the balance program **808**, the scale database **810** is initially loaded in a select specimens step **812** with counterparts of container indicia **104**, and with data for a common spin cycle **1002** associated therewith, the corresponding containers **12** being in a quantity appropriate for simultaneous centrifugation by the centrifuge unit **1000**. Next, in a tare step **814**, an appropriate complement of receptacles **1200** for holding the containers **12** is identified, and seated if necessary, at respective sites on the scale platform **802**. A total load on the scale **802** is measured fallowing the depositing of each item on the scale **802**, a difference between successive measurements representing each particular added load. Following the tare step **814** is a load step **816**, wherein the containers **12** to be centrifuged are sequentially placed in respective ones of the receptacles **1200** according to an appropriate one of the patterns of Figs. 11A-11D, depending on the number of the containers **12** to be centrifuged. The balance program **808** continues monitoring the loads added to the scale **802** during the load step **816**. Thus the balance program **808** is operative for monitoring the total weight associated with each of the receptacles **1200**. After the load step **818**, appropriate ones of the dummy loads **806** are added in a correction step **820** as required to bring members of each pair of the receptacles **1200** to within the predetermined allowable variation.

Decapper System

With particular reference to Figs. 18A and 18B, the decapper system **900** includes a receiver **902** for clampingly holding a container or test tube **102** having a cap **103** frictionally engaging the test tube **102** and extending laterally from opposite sides of a top portion of the test tube **102**. The receiver **902** is mounted in depending relation to a decapper deck insert **903** of the workstation **100** as further described below. An important aspect of the present invention is that the decapper system **900** is operative

with both threadingly engaged caps as described below, and with caps having frictional engagement only with the container **12** as described herein. A yoke member **904** having a cap slot **905** formed therein is movably mounted on an elevator **906** that projects above the deck insert **903**, being supported thereby. The elevator **906** includes an actuator **908** and an elevator column **909** that is rigidly connected to the yoke member, the actuator **908** being coupled to a translation motor **910** through a translation belt **911** for rotational translation of the yoke member **104** concentric with the elevator column **909** between open and closed positions thereof. The elevator **906** is also coupled to an elevator motor **912** through an elevator belt **913** for raising and lowering the elevator column together with the yoke member **904**. The yoke member **904** has an upwardly facing ledge portion **916** formed within the cap slot **905** for engaging the underside of an outwardly extending shoulder surface **917** of the cap **103** when the cap **103** is seated in the test tube **102**, the tube **102** being held in the receiver **902**, in the closed position of the yoke member **904**.

With the ledge portion **916** extending under the shoulder surface **917** in the closed position of the yoke member **904**, the elevator **906** is operative for raising the yoke member **904** relative to the receiver **902** to thereby remove the cap **103**. The receiver **902** includes a bladder cage **920** for rigidly supporting a bladder **921**, the bladder **921** having a gas port **922** for selective inflation from a suitable pressure source, described below, thereby to grip a test tube **102** being seated therein. Thus the receiver **902** is operative for holding the container **12** against axial forces exerted by the yoke member **904** as the cap **103** is being pulled from the container **12**.

As mentioned above, a further important capability of the decapper system **900** is removal of threadingly engaged caps **103**. Accordingly, the bladder cage **920** is rotatably mounted to the deck insert **903**, being coupled to a rotation motor **924** through a rotation belt **925** for controllably turning the bladder **921** concentrically with the container **102**, thereby to unscrew the container **12** from the cap **103**. The cap **103** is prevented from rotation within the yoke member **904**, being formed with a non-circular outer contour having an enlargement **927** formed thereon, the enlargement **927** of the cap **103** bearing against a portion of the cap slot **905** when torque is applied to the container **12** by the retainer **902**. The gas port **922** is preferably configured to provide a rotary connection to the bladder **921**, the port **922** being connected to a three-way

control valve **928** through a cage line **929** for selective pressure activation in response to the central controller **500** to effect the above-described holding of the containers **12**.

With further reference to Fig. 18F, a preferred alternative of the bladder cage, designated clamp cage **920'**, includes a resilient sleeve **921'** in place of the bladder **921**, the sleeve **921'** having three outwardly projecting ears **926** that engage respective ear slots **929** of the cage **920'** to insure rotational integrity of the sleeve **921'** with the cage **920'**. Three vertically oriented jaws **913** are spaced between the ears **926** together with corresponding cam bars **914**, the bars **914** resting on a disk plate **915**. An air cylinder **918** that is coupled by the fitting **922** to the control valve **928** through the cage line **929** drives the disk plate **915** and the bars **914** upwardly. The bars **914** have a spaced pair of cam slots **914A** that engage corresponding pins **914A** that project from the jaws **913**, thereby driving the jaws **913** inwardly in response to the upward movement of the bars **914** for compressing the sleeve **921'** against the test tube **102**. The sleeve **921'** is closed at the bottom for confining debris in case a test tube **102** is fractured therein. Also, the sleeve **921'** has ribs **923** formed therein for contacting the test tube **102**, including three full-length clamp ribs **923A** that are aligned with the jaws **913** and three foreshortened holder ribs **923B**. Spaces between the ribs **923** contribute flexibility to the sleeve **921'** for enhanced effectiveness of the jaws **913** in gripping the test tubes **102**. Test tubes **102** that are 100mm in length normally extend to proximate the bottom of the sleeve **921'**, while test tubes **102** having a length of 75mm are normally inserted only partway into the sleeve **921'** as indicated by broken lines in Fig. 18F, the holder ribs **923B** being configured for retention of the shorter test tubes **102** partially inserted, without adding unnecessarily to the axial forces required for full insertion and withdrawal of the 100mm test tubes **102**.

Preferably the decapper system also includes a collector **930** for receiving caps **103** from the yoke member, and an unloader **932** for transferring removed caps from the yoke member **904** to the collector **930**. An exemplary implementation of the unloader includes an upstanding unloader post **934** fixedly mounted to the deck insert **903** proximate the collector **930**, in alignment with the cap slot **905** in the open position of the yoke member. A decapper program portion of the central controller **500** is operative for moving the yoke member **904**, having a removed cap **103** therein, until the post **934** strips the cap **103** from the yoke member. Preferably, the collector **930** further includes a tube member **936** for directing the stripped caps **103** into the collector **930**.

With further reference to Figs. 18C-18E, an alternative and preferred configuration of the decapper system, designated **900'**, includes a yoke housing **938** having a bottom cover **939** as a counterpart of the yoke member **904**, a clamp mechanism **940** being operative within the housing **938** for positively gripping the caps **103**. As shown in Fig. 18E, the clamp mechanism **940** has an opposed pair of pivotally mounted jaws **942** that are operated by a pneumatic cylinder **944** having a wedge-shaped cam actuator **946** that extends from the cylinder **944** in response to applied gas pressure. The jaws **942** are each formed having a plurality of projections **943** therein for gripping opposite sides of the caps **103** when same are positioned within the cap slot **905**. The yoke housing **938** is formed having a passage **948** therein from the cylinder **944** to a fitting **949** that projects below the cover **939** for connecting a flexible line **950**, the line **950** extending below the deck insert **903** to a three-way valve **952**. The valve **952**, being connected by a decapper line **870** to the pneumatic system **850** (Fig. 19) as is the valve **928** described above, is operative for activating the pneumatic cylinder **944** in response to the central controller **500** to effect gripping of the caps **103**. Thus the caps **103** are not required to have enlargements **927** or to otherwise have a rotationally interfering fit with the cap slot **905**. Further, the caps **103** are not required to have the outwardly projecting shoulder surface **917** (Fig. 18A) in the preferred decapper **900'**.

As further shown in Figs 18C and 18D, the decapper system **900'** includes a counterpart of the unloader **932** on the yoke housing **938**, in the form of a plunger assembly **954**. The plunger assembly **954** includes a shouldered plunger **955** that is guided within an ejector support **956**, the plunger **955** having an upwardly projecting stem **957** that slidingly engages the support **956**, an ejector spring **958** being interposed on the stem **957** for downwardly biasing the plunger **955** against the yoke housing **938**. A cap **103** being released from the jaws **942** by deactivation of the valve **952** is forcefully extracted from the cap slot **905** by axial movement of the plunger **955** into engagement with the yoke housing **948**. Thus caps **103** are prevented from sticking to the projections **943** of the jaws **942** when the clamp mechanism **940** is opened, for reliable unloading into the collector **930**.

The controller **500** is programmed for driving the elevator **906** sufficiently high for the plunger **955** to clear the cap **103** as the cap slot **905** is rotated into position over the cap **103**, then lowering the yoke housing **938**, thereby compressing the ejector

spring **958** as the jaws **942** are lowered into a desired alignment with the cap **103**, the cap **103** supporting the plunger **955**. Next, the clamp mechanism **940** is closed by activation of the valve **952**, the jaws **942** gripping the cap **103**, and operation of the decapper **900'** continues as described above in connection with the decapper system **900** of Figs. 18A and 18B.

As further shown in Fig. 18B, the tube member **936** is provided with a cap detector **959** for signaling the controller **500** upon each passage of a cap **103** into the collector **930**. Thus appropriate corrective action can be taken in the event that processing a capped container **12** by the decapper system **900'** fails to result in detected passage of the cap **103** into the collector **930**.

As shown in Fig. 19, the workstation **100** is provided with a pneumatic circuit or gas pressure system **850** having a plug connection **851** to a suitable source **852** of pressurized gas, the gas being fed through an inlet filter **853** to an accumulator reservoir **854** of approximately 22 liters capacity, a one-way inlet valve **855** being provided for maintaining pressure when the source **852** is inactive. A main solenoid valve **858** and a pressure transducer **859** are series-connected between the inlet filter **853** and the inlet valve **855**, the transducer **859** signaling the normal presence of gas pressure at approximately 5 atmospheres. The rail **26** of the track **704** is utilized as the reservoir **854**, the rail **26** advantageously providing large capacity and extending substantially the full length of the workstation **100** for enabling relatively short pneumatic connections.

A distribution manifold **860** is connected to the reservoir **854** for feeding pneumatic elements of the workstation **100** as described herein. In a bearing branch **861** from the manifold conduit **860**, a moisture filter **862**, a pressure regulator **863** having an oil filter **864** and a pressure indicator **865**, and a pressure transducer **866** are series-connected for feeding air bearings of the track **704** of the workstation robot arm **700**, the transducer **866** signaling a normal pressure of approximately 4.5 atmospheres. A brake branch **867** from the manifold **860** has a solenoid brake valve **868** connected therein for activating a track brake of the track **704**. A counterpart of the pressure regulator, designated **869**, is connected in a decapper branch **870** from the manifold conduit **860** for feeding the decapper system **900**. A shield branch **871** from the manifold **860** having another regulator, designated **872**, feeds a trio of door valves **873** for controlling the

pneumatic actuators **52** of the shield system **40**. A pair of adjuster valves **874** being mounted to the rail **26** of the track **704** for fluid connection to the reservoir **854** for selectively releasing the delivery site adjusters **961**, the valves **874** being connected by respective adjuster lines **875** to corresponding gas ports **971** of the adjusters **961**. Finally, a pair of side loader branches **876** of the manifold conduit **960** have corresponding counterparts of the valves **874**, designated manually activated valves **878**, therein for feeding pneumatic components of the analyzers **2000**, includung the analyzer robotic arms **2002**.

Centrifuge Unit

As described above, the centrifuge unit **1000** receives the specimens in containers **120** that have been loaded into receptacles **1200**, subjecting the specimens to a specified spin cycle **1002** prior to further processing in the analyzer **2000**. With particular reference to Fig. 16A, the centrifuge unit **1000** provides a plurality of load stations **1004** on respective cradles **1008** of a rotatably driven spindle head **1006** for receiving a balanced complement of the receptacles **1200** within a spin chamber **1010** of the centrifuge unit **1000**. As used herein, "receptacle" includes buckets **1200**, but broadly means a device for holding a fluid specimen within a centrifuge and during transport of the specimen into and out of the centrifuge. Thus "receptacle" can stand for (1) a single test tube, vial or other container when the container is loadable directly into a centrifuge head cavity; or (2) a rack, sector, or other holder for one or more containers when the containers are in such holders during centrifugation.

An exemplary embodiment of the centrifuge unit **1000** includes a cabinet **1012** having a chamber opening **1014** for accessing the spin chamber **1010**, a spindle unit **1016** being supported within the cabinet **1012** under the opening **1014** for driving the spindle head **1006**, the cradles **1008** being pivotally mounted to the spindle head **1006** as indicated by pairs of bearing caps **1009**. The cabinet **1012** includes a wheeled base frame **1018** having a base plate **1020** fastened thereon, a plurality of body panels including respective pairs of side panels **1022** and end panels **1024** surrounding the frame **1018** and extending upwardly from the base plate **1020**, and a deck panel **1026**, the deck panel **1026** extending between upper extremities of the body panels **1024** and **1026**. A chamber bezel **1028** having the chamber opening **1014** formed therein covers a portion of the deck panel **1026**, an access panel **1030** also covering a portion of the

deck panel **1026**, the deck panel **1026** having an opening (not shown) that corresponds to the chamber opening **1014**, and another opening (not shown) under the access panel **1030** for service access to interior portions of the cabinet **1012**.

According to the present invention, the centrifuge unit **1000** includes a horizontally oriented door member **1032** that is laterally movable under the chamber bezel **1028** between an open position as shown by solid lines in Fig. 16A, and a closed position as indicated by dashed lines. The open position of the door member **1032** provides access to the spin chamber **1010**, the closed position blocking such access for protecting against accidental contact with the spindle head **1006** and contents thereof during operation of the centrifuge unit **1000**. The door member is supported within a door frame **1034**, the frame **1034** being rigidly spaced above the base plate **1020** on a plurality of column members **1036**. The door member **1032** is driven between the open and closed positions by a frictionally coupled door actuator **1038** as further described below, the actuator **1038** advantageously protecting personnel from being injured in case of inadvertently reaching through the cavity opening **1014** while the door member **1032** is moving to the closed position, by limiting the application of actuating force to the door member **1032**. As further shown in Fig. 16A, the centrifuge unit **1000** can include an input keyboard **1040** and a CRT display **1042** for interfacing with an operator of the unit **1000**.

With further reference to Figs. 16B-16E, a preferred alternative configuration of the centrifuge unit **1000** has a smaller counterpart of the cabinet (not shown) with counterparts of the door member, designated **1032'**, and the door frame, designated **1034'**, whereby access through the chamber opening **1014** to the spin chamber **1010** is normally through a reduced-size access opening **1044** for facilitating rapid opening and closing of the door member **1032'**. As shown in Fig. 16B, the door panel **1032'** is supported within a removable door module **1046** between an upper or outer tray member **1048** and a lower or inner tray member **1050**, vertically aligned counterparts of the opening **1044** being formed in each of the tray members **1048** and **1050**. The access opening **1044** is sufficiently large for passing one of the receptacles **1200** vertically therethrough into seating engagement with one of the load stations **1004** when that load station **1004** is indexed to a loading position as described below. More particularly, the tray members **1048** and **1050** of the door module **1046** are fastened to

opposite sides of respective spacers **1052**, a handle **1054** being mounted on one of the spacers **1052** for horizontally withdrawing the door module **1046** from the frame **1034'**, thereby to fully expose the spin chamber **1010** through the chamber opening **1014**. It will be understood that access to the door module **1046** can be provided by any suitable means, such as removal of the associated end panel **1024**.

As further shown in Fig. 16B, the door frame **1034'** includes a support plate **1056** that extends between upper extremities of the column members **1036**, a spaced pair of side rails **1058** being rigidly fastened along opposite sides of the support plate **1056** for laterally locating the door module **1046**. As shown in Fig. 16C, the door actuator **1038** includes a friction drive wheel **1060** that is rotatably supported by a drive housing **1062**, a stepper motor **1064** being coupled thereto. The drive wheel **1060** has a resilient ring member **1066** formed thereon for biasingly contacting an edge surface **1068** of the door member **1032'** thereby to translate the door member **1032'** between the open and closed positions thereof.

An important feature of the door actuator **1038** is that the drive wheel **1060** is not positively coupled to the door member **1032'**, making sliding contact therewith in case movement of the door member **1032'** is blocked, for example, by laboratory personnel reaching into the spin chamber **1010** as the door member **1032'** is being driven toward the closed position. The door member **1032'** is movably supported within the door module **1046** by a plurality of guide rollers **1070** that engage a pair of tracks, designated primary track **1072** and secondary track **1073**, the tracks **1072** and **1073** being fastened to the inner tray member **1050**.

As further shown in Fig. 16C, the door member **1032'** is supported both vertically and horizontally relative to the primary track **1072**, horizontally oriented ones of the rollers **1070** being mounted by respective threaded fasteners **1070A** to the door member **1032'**, vertically oriented ones of the rollers **1070** being supported on respective rods **1070B** that are clamped to the door panel **1032'** by corresponding retainer plates **1070C**. The housing **1062** is adjustably mounted to the door frame **1034'** by suitable fasteners **1074** for providing a desired degree of coupling between the drive wheel **1060** and the edge surface **1068**.

As further shown in Figs. 16B and 16D, a solenoid-operated latch **1076** is mounted to the door frame **1034'** for locking the door member **1032'** in the closed

position thereof, the door member **1032'** having an opening **1078** formed therein for engagement by the latch **1076**. Also, a slot **1079** is formed in the inner tray member **1050** and one of the spacers **1052** for permitting withdrawal of the door module **1046** when the latch **1076** is retracted from the door member **1032'**. It will be understood that the door actuator **38** as described above is suitable for driving the door member **1032** of Fig. 16A as well as the door member **1032'** of Fig. 16B, counterparts of the guide rollers **1070** also being suitable for supporting of the door member **1032** of Fig. 16A.

As shown in Fig. 16D, the centrifuge unit **1000** includes a control circuit **1080** for operating the spindle unit **1016**, the drive unit **1038**, and the latch **1076**, a pair of optical position sensors being located relative to the door frame **1034'** for signaling the open and closed positions of the door member **1032'**, a first sensor **1081** signaling the closed position, a second sensor **1082** signaling the open position of the door member **1032'**.

The spindle unit **1016** includes the spindle head **1006**, a spindle assembly **1084** having a spindle shaft **1085** for rotatably supporting the spindle head **1006** within the spin chamber **1010**, the spindle assembly **1084** also having a spindle housing **1086** that is supported from the base plate **1020**. A spindle motor **1088** is coupled to the spindle shaft **1085** in a conventional manner, the motor **1088** being fixedly supported relative to the base plate **1020** by any suitable means.

An important feature of the present invention is that the spindle unit **1016** is capable of indexing each of the load stations **1004** into alignment with the access opening **1044** for receipt and delivery of the receptacles **1200**, the spindle head **1006** coming directly and rapidly to a halt in a predetermined one of the indexed positions at the conclusion of any desired spin cycle. Accordingly, the spindle motor **1088** is provided with a position encoder **1090** for signaling angular positions of the spindle head **1006**. In an exemplary and preferred configuration of the control circuit **1080** shown in Figs. 16D and 16E, the spindle motor **1088** is a four-pole brushless AC servo motor, a motor of this type being Model SGM-00A3 Servomotor, available from Yaskawa Electric America, Inc., of Northbrook, IL. The above-identified motor includes the encoder **1090** having a quadrature incremental count output **1091** of 2048 pulses/rev., and an index pulse output **1092**. As also shown in Fig. 16D, the control system **1080** also includes a centrifuge processor **1093**, a motion processor **1094**, and a motor driver **1095**, the

motion processor **1094** being responsive to the encoder **1090** and position setpoint signals from the centrifuge processor **1093** for feeding acceleration control signals to the motor driver **1095**, thereby driving the motor **1088** from an indexed initial rest position to a programmed spin velocity, holding that velocity for a programmed spin duration, then decelerating the motor **1088** to rest at a predetermined final rest position.

Suitable devices for use as the centrifuge processor **1093** are commercially available from a variety of sources, one such being a STD-32 486 CPU Board, available from Ziatech of San Luis Obispo, CA. A device suitable for use as the motion processor **1094** is available as Model STD/DSP Motion Controller from Motion Engineering, Inc. Of Santa Barbara, CA. This device processes the quadrature signals of the count output **1091** for feeding a position register with 8192 counts per revolution of the spindle motor **1088**, the device also having a destination register that is loaded from the centrifuge processor **1093**, and a digital to analog converter (DAC) that generates an analog output as a function of the difference between the position register and the destination register and other variables including maximum velocity and acceleration. It will be understood that the above-identified motor and motor driver would not ordinarily be considered suitable for use as the spindle motor **1088** and the motion processor **1094**, in that the rated allowable load inertia is only 0.189 oz-in-sec^2 (0.836×10^{-4}), being a factor of approximately 250 below what is practically feasible in the centrifuge unit **1000** of the present invention. In accordance with the present invention, it has been discovered that the above-identified motor and motor driver are suitable for use in the centrifuge **1000**, with a suitable compensating filter **1096** connected between the motion processor **1094** and the filter **1095**. Primarily, the compensating filter **1095** provides a "notch" frequency response, the notch being centered at approximately 75 Hz.

As further shown in Fig. 16D, the control circuit **1080** also includes a stepper motor driver **1098** for operating the stepper motor **1064** of the door actuator **1038** in response to the centrifuge processor **1093**. A device suitable for use as the stepper motor driver **1098** is available as Model 4831 2 Microstepping Driver from Intelligent Motion Systems, Inc. of Taftville CT. The centrifuge processor **1093** also has a system interface **1099** for communication with the process controller **400**. It will be understood that the keyboard **1040** and the display **1042** in the configuration of Fig. 16A have conventional interfaces (not shown) with the centrifuge processor **1093**, those

components not being required when the processor **1093** is interfaced with the process controller **400**. The actual connections among the components of the control circuit **1080** are best shown in Fig. 16E, the circuit **1080** further including a conventional STD-32 cardcage **1100** for the centrifuge processor **1093** and the motion processor **1094**, an EMI filter **1102** having means for connection to an external source of electrical power, a main power supply **1104** and a stepper power supply **1106** for the stepper motor controller **1098**, the power supplies **1104** and **1106** being powered from the EMI filter **1102**, a regeneration unit **1108** for the motor driver **1096**, and an I/O board **1110** that provides principal interconnections between components of the control circuit **1080**. The regeneration unit **1108** absorbs energy that is recovered from the spindle motor **1088** during deceleration, for limiting unwanted power dissipation by the motor drive **1095**. A device suitable for use as the regeneration unit **1108** is available as Model JUSP-RG08 Regenerative unit, from Yaskawa Electric. The I/O board **1110** also incorporates the compensating filter **1096** and conventional buffer circuits for the sensors **1081** and **1082**, and for the solenoid latch **1076**, as shown in Fig. 16F. More particularly, the compensating filter **1096** includes a twin-T filter **1112**, a low-pass operational amplifier **1114**, a two-stage low-pass filter **1116**, and a buffer amplifier **1118**, these elements being series-connected between the previously introduced analog output, designated **1120**, of the motion processor **1094** and a torque command input **1122** of the motor driver **1095**.

Figure 16G depicts a control program **1130** of the centrifuge processor **1093**, the program **1130** having an initialization procedure **1131** wherein both program and data information is loaded into memory of the motion processor **1094**, serial communications are established between the processor **1093** and the stepper motor drive **1098**, default variable values are stored in variable memory of the processor **1093**, and action flags are reset. The initialization procedure **1031** is followed by a main loop **1132** having a get command step **1133** for receiving commands and data from the process controller **400**. In an exemplary implementation of the program **1130**, the executable commands are listed in Table 1, below.

Table 1, Centrifuge Commands	
Command Code	Command Name
IM	Index Move
SA	Set Acceleration
SV	Set Velocity
ST	Set Time
BR	Begin Run
HD	Home Door
HM	Home Motor
ER	Stop
VS	Get Velocity Status
RS	Get Rotor Status
OD	Open Door
CD	Close Door

In the following description, it will be understood that many details of the control program **1130** are within the skill of ordinary process control programmers. For example, the get command step **1133** appropriately stores data accompanying several of the commands, the commands being processed only when completely received, with control being passed from the command step during execution of time-consuming commands for continuous status monitoring by the control program **1130**. The get command step **1133** is followed by an execute command step **1134** that initiates execution of the command, and sets appropriate flags and the like. Execution of the Home Motor command is performed in a spindle homing procedure **1135** wherein the spindle head **1006** is advanced to a home index station wherein the load station **1004A** is aligned with the access opening **1044**, as determined by activation of the index output **1092** of the encoder **1090**. The spindle homing procedure **1135** includes an advance step **1136** wherein the spindle head **1006** is advanced at a moderate velocity until the head **1006** passes an index position at which the index output is activated; a reverse step **1137** wherein the spindle head **1006** is stopped, then reversed at a small fraction (1/25) of the moderate velocity of the advance step **1136**; and an offset step **1138** wherein the spindle head **1006** is again stopped and then advanced beyond the index

position by an offset distance. The index position is intentionally angularly displaced from the load station **1004A**, for activation of the index output **1092** in the advance step **1133** preferably slightly prior to alignment of the load station **1004A**. Thus the offset distance can be made advantageously small for rapid completion of the offset step **1138**.

Execution of the Index Move command is performed by an index function **1140**, wherein the load stations **1004A**, **1004B**, **1004C**, and **1004D** are addressed by corresponding digits 1, 2, 3, and 4, and the spindle head is advanced (algebraicly) by the difference between a presently indexed position and the addressed station, the difference being the number of encoder counts between stations times zero, one, two, or minus one.

Execution of the Begin Run command is performed in a begin run procedure **1142**, wherein data of the spin cycle **1002** is used to calculate a destination distance as a sum of an acceleration distance and a constant velocity distance, the acceleration distance being the combination of both acceleration and deceleration distances. More particularly, the constant velocity distance, D_V is the product of the velocity V and time T of the spin cycle **1002**, and the acceleration distance is V^2/A, where A is a predetermined acceleration, A, V, and T having been previously defined by corresponding ones of the above-identified commands. These distances are summed, then offset by a distance corresponding to the presently indexed position relative to the home position, the result being signalled to the motion board **1094** for activation of the spindle motor **1088**. Accordingly, the spindle head **1006** is accelerated at the commanded acceleration to the commanded spin velocity, the spin velocity being maintained for the commanded spin time, the spindle head **1006** being then decelerated at the commanded acceleration to rest at the home position.

Execution of the Home Door command is performed in a home door procedure **1144** having a check home step **1145** and a move home step **1146**. The procedure **1144** is exited from the check home step if the first sensor is activated, signifying the door being closed; otherwise, the move home step **1146** is entered for activating the stepper motor driver **1098** to advance the stepper motor **1064** at a slow homing velocity (100 steps/sec.) toward the closed position.

Execution of the Open Door and Close Door commands is performed in a door function **1148**, in corresponding opening and closing steps **1149** and **1150**. In the closing step **1150**, the stepper motor **1064** is caused to be driven 1200 steps toward the closed position at 1500 steps/sec., followed by further movement at 50 steps/sec. until the home (closed) position is sensed. In case door movement is hindered by blockage as described above, damage of the centrifuge unit **1000** and/or injury to laboratory personnel is prevented by the drive wheel **1060** slipping against the edge surface **1068** of the door member **1032'** as described above. Similarly, the opening step **1149** operates with opposite activation of the stepper motor **1064**, until the second sensor **1082** signals the open position of the door member **1032'**.

System Software

A preferred software implementation of the process supervisor **200** and incorporating a graphical user interface (GUI) is based on the Lab-View ™ software development package, available from National Instrumentation Corp. of Austin, TX. In this implementation, maps of the system **10**, including the workstation **100** and the centrifuge **1000**, for example, are displayed, together with various status indicators and controls. Map displays show the locations of all of the holders **14**, and by clicking on a particular holder, its identification is displayed and a map of the containers **12** therein is available. Conversely, the location of a particular container **12** can be searched by entering its identification. This implementation is available as AccelNet software from Beckman Instruments.

Although the present invention has been described in considerable detail with reference to certain preferred versions thereof, other versions are possible. For example, as an alternative to the shield system **40** or in addition thereto, the workstation **100** can be provided with detectors to detect presence of an operator in a portion of the workbench which can be dangerous to the operator, to automatically stop operations, as is typically used in industrial machinery. This can be a device such as light beam and a light beam detector, shutdown of the workstation being triggered by interruption of the light beam. Therefore, the scope of the appended claims should not be limited to the description of the preferred versions contained herein.

What is claimed is:

1. A system for automatically processing multiple containers containing specimens, at least some of the containers having a cap, each of the containers having container identification indicia thereon, the containers being held in a holder, the system comprising:

(a) a central controller comprising (i) memory storage and (ii) a data input element for inputting instructions for processing of each container according to the container identification indicia, the processing instructions being stored in memory;

(b) detectors for detecting the presence of a holder in the system, the detectors having an output element for signaling the presence of a holder to the central controller;

(c) an indicia reader for reading the container identification indicia, the reader having an output element for providing the container identification indicia to the central controller;

(d) a container sorting system comprising (i) a data input element in communication with the central controller for receiving instructions from the central controller for sorting containers for selective processing according to the processing instructions stored in the central controller memory storage, and (ii) a plurality of sort sites for placement of containers according to their processing instructions;

(e) a centrifugation system for centrifugation of selected specimens, the centrifugation system comprising:

(i) receptacles for receiving multiple containers; and

(ii) a centrifuge for simultaneously centrifuging multiple receptacles, the centrifuge having a motor, a centrifuge controller for stopping the centrifuge at selected positions for automated removal of receptacles from the centrifuge in response to signals from the central controller, a lid with a closed position and an open position, and a lid drive for opening and closing the lid in response to instructions from the central controller;

(f) a receptacle balance system for balancing receptacle weight for the centrifuge;

(g) a decapper system for selectively decapping containers;

(h) at least one analyzer for selectively analyzing the specimens; and

(i) a transport system for (i) transporting containers to and from the centrifuge receptacles, the analyzer, and the decapper system, (ii) transporting receptacles to and from the receptacle balance system and the centrifugation system, and (iii) transporting containers in the sorting system, the transport system having a controller in communication with the central controller so that the central controller can control the transport system.

2. The system of claim 1, further comprising a process supervisor having:

(a) a programmed detect input step for determining introduction of containers at an input location on the workstation;

(b) a container select step in which detected containers are selected for processing;

(c) an identification step for defining process components for each selected container according to the container identification indicia, and

(d) a process select step for initiating the defined process components being one or more of sorting, centrifugation, decapping, and analysis.

3. The system of claim 1 wherein each analyzer comprises:

(a) a mechanism for selectively performing at least two different analyses on a specimen;

(b) an analyzer controller in communication with the central controller so that the central controller can instruct the analyzer as to what analysis to perform for each specimen; and

(c) an output system for providing analysis results to memory of the central controller.

4. The system of claim 1 or 3, comprising two analyzers, wherein each output system has an output element for providing analyzer availability information to the central controller, and the central controller has means for selectively determining which analyzer each specimen that is to undergo analysis is analyzed by.

5. The system of claim 1, wherein the transport system comprises a first robotic arm for transporting containers to and from the analyzer, and a second robotic arm.

6. The system of claim 5, further comprising a shield system for selectively blocking operator access to the workstation, the shield system including a partition that encloses the top of the workstation and having an opening for passage of the analyzer robotic arm, an enlargement for passage of receptacles to the centrifuge, an access door having an actuator, and an operator input device for signaling access requests to the central controller, the controller being operative for appropriately inhibiting operation of the workstation robotic arm and then activating the actuator for opening the door following operator input.

7. The system of claim 1, wherein the system includes multiple input locations for placement of the containers, each of the input locations having a detector, at least one of the locations being for priority containers, wherein the detector output element signals the presence of priority containers to the central processor, and wherein the central processor provides instructions for priority processing of priority containers.

8. The system of claim 1, wherein the container holders have holder identification indicia thereon, and wherein the indicia reader can read the holder identification indicia, the reader output element providing the holder identification indicia to the central controller for tracking containers according to their respective holders.

9. A system for automatically processing multiple containers containing specimens, each of the containers having container identification indicia thereon, the containers being held in a holder having holder indicia thereon, the system comprising:

(a) a central controller comprising (i) memory storage and (ii) a data input element for inputting processing instructions for the processing of each container according to the container identification indicia, the processing instructions being stored in memory;

(b) detectors for detecting the presence of a holder in the system, the detectors having an output element for signaling the presence of a holder to the central controller memory storage;

(c) an indicia reader for reading the container identification indicia and the holder identification indicia, the indicia reader having an output element for providing the container identification indicia and the holder identification indicia to the central controller memory storage; and

(d) a container sorting system comprising (i) a data input element in communication with the central controller for receiving instructions from the central controller for sorting containers for selective processing according to the processing instructions stored in the central controller memory storage, and (ii) a plurality of sort sites for placement of containers according to their processing instructions.

10. A system for automatically preparing multiple containers containing specimens, comprising:

(a) a centrifugation system for centrifugation of selected specimens, the centrifugation system comprising:

(i) receptacles for receiving multiple containers; and

(ii) a centrifuge for simultaneously centrifuging multiple receptacles, the centrifuge having a motor, a centrifuge controller for stopping the centrifuge at selected positions for automated removal of receptacles from the centrifuge in response to signals from the central controller, a lid with a closed position and an open position, and a lid drive for opening and closing the lid in response to instructions from the central controller;

(b) a receptacle balance system for balancing receptacle weight for the centrifuge; and

(c) a transport system for (i) transporting containers to and from the centrifuge receptacles, and (ii) transporting receptacles to and from the receptacle balance system and the centrifugation system.

11. A workstation for automatic preparation of multiple containers containing specimens for analysis, the workstation operating in cooperation with a centrifuge and a controller, the centrifuge being capable of centrifuging multiple receptacles containing containers, at least some of the containers having a cap, each of the containers having container identification indicia thereon, the containers being held in holders, the workstation comprising:

(a) a table;

(b) holder positioners on the table for positioning the holders in predetermined locations;

(c) receptacle positioners on the table for positioning receptacles;

(d) detectors for detecting the presence of a holder on the table at the predetermined locations, the detectors having an output element for signalling the presence of a holder to the controller;

(e) an indicia reader for reading the container identification indicia, the reader having an output element for providing the container identification indicia to the controller;

(f) a receptacle balance system on the table for balancing the weight of receptacles containing containers for the centrifuge;

(g) a decapper on the table for selectively decapping centrifuged containers;

(h) a delivery site on the table for placement of holders containing centrifuged, decapped containers for analysis by the analyzer and a receiving site on the table for receiving analyzed samples from the analyzer;

(i) a transport system on the table (i) for transporting containers to and from the centrifuge receptacles, the delivery and receiving sites, and the decapper, (ii) for sorting containers for processing, and (iii) for transporting receptacles to and from the receptacle balance system and the centrifuge, the transport mechanism having an input element in communication with the controller so that the controller can control the transport system.

12. A workstation for automatic preparation of multiple containers containing specimens for analysis, the workstation operating in cooperation with a centrifuge and a controller, the centrifuge being capable of centrifuging multiple receptacles containing containers, at least some of the containers having a cap, each of the containers having container identification indicia thereon, the workstation comprising:

(a) a table;

(b) holders on the table for holding the containers in predetermined locations;

(c) receptacle positioners on the table for positioning receptacles;

(d) an indicia reader for reading the container identification indicia, the reader having an output element for providing the container identification indicia to the controller;

(e) a receptacle balance system on the table for balancing the weight of receptacles containing containers for the centrifuge;

(f) a decapper on the table for selectively decapping centrifuged containers;

(g) an analyzer delivery site on the table for receiving centrifuged, decapped containers for analysis by the analyzer and an analyzer receiving site on the table for receiving analyzed samples from the analyzer; and

(h) a transport system on the table for (i) transporting containers to and from the centrifuge receptacles, the analyzer delivery and receiving sites, and the decapper, (ii) sorting containers for processing, and (iii) transporting receptacles to and from the receptacle balance system and the centrifuge, the transport mechanism having an input element in communication with the controller so that the controller can control the transport system.

13. A workstation for automatic sorting of multiple containers containing specimens for analysis, the workstation operating in cooperation with a controller, each of the containers having container identification indicia thereon, the containers being held in holders, the workstation comprising:

(a) a table;

(b) holder positioners on the table for positioning the holders in predetermined locations;

(c) detectors for detecting the presence of a holder on the table at the predetermined locations, the detectors having an output element for signalling the presence of a holder to the controller;

(d) an indicia reader for reading the container identification indicia, the reader having an output element for providing the container identification indicia to the controller; and

(e) a transport system on the table for sorting containers for processing according to indicia on the containers, the transport mechanism having an input element in communication with the controller so that the controller can control the transport system.

14. A workstation for automatic preparation of multiple containers containing specimens for analysis, the workstation operating in cooperation with a

controller and at least one analyzer, the containers having container identification indicia thereon, the containers being held in holders, the workstation comprising:

(a) a table;

(b) detectors for detecting the presence of a holder on the table at the predetermined locations, the detectors having an output element for signalling the presence of a holder to the controller;

(c) an indicia reader for reading the container identification indicia, the reader having an output element for providing the container identification indicia to the controller;

(d) an analyzer delivery site on the table for placement of holders for analysis by the analyzer and an analyzer receiving site on the table for receiving analyzed samples from the analyzer; and

(e) a transport system on the table for (i) transporting containers to and from the analyzer delivery and receiving sites, and (ii) sorting containers for processing, the transport mechanism having an input element in communication with the controller so that the controller can control the transport system.

15. The workstation of claim 14, wherein the transport system comprises a robotic arm on a longitudinal track, and the table includes a base, the base comprising:

(a) a plurality of rigid bulkheads;

(b) a pair of longitudinal beams connecting respective opposite sides of the bulkheads; and

(c) a longitudinal rail connecting respective column extremities of the bulkheads in vertically spaced relation between the beams, the track being supported on the rail.

16. The workstation of claim 15, wherein the workstation further comprises a pneumatic subsystem for the transport system, the rail forming a reservoir of the pneumatic subsystem.

17. A workstation for automatic preparation of multiple containers containing specimens for analysis, the workstation operating in cooperation with a centrifuge and a controller, the centrifuge being capable of centrifuging multiple receptacles containing containers, at least some of the containers having a cap, each of

the containers having container identification indicia thereon, the containers being held in holders, the workstation comprising:

(a) a table;

(b) detectors for detecting the presence of a holder on the table, the detectors having an output element for signalling the presence of a holder to the controller;

(c) an indicia reader for reading the container identification indicia, the reader having an output element for providing the container identification indicia to the controller;

(d) a receptacle balance system on the table for balancing the weight of receptacles containing containers for the centrifuge; and

(e) a transport system on the table for (i) transporting containers to and from the centrifuge receptacles, (ii) sorting containers for processing, and (iii) transporting receptacles to and from the receptacle balance system and the centrifuge, the transport mechanism having an input element in communication with the controller so that the controller can control the transport system.

18. A system for automated analysis of specimens in containers comprising:

(a) a workstation for preparation of specimens for analysis, the workstation having a front, a rear, and opposed sides;

(b) an analyzer for analysis of specimens prepared by the workstation, the analyzer having opposed sides, a front, a top, and a back, the top having analytical equipment thereon and being accessible from the front by a user; and

(c) a transport mechanism for automated transport of specimens from the workstation to the analyzer,

wherein the workstation is proximate to one of the sides of the analyzer without any obstruction of the front of the analyzer.

19. A system for automated analysis of specimens in containers comprising:

(a) a workstation for preparation of specimens for analysis, the workstation having a top, the top having a delivery site for placement of containers for analysis by the analyzer and a receiving site for receiving analyzed samples from the analyzer;

(b) an analyzer for analysis of specimens prepared by the workstation; and

(c) a robotic arm on the analyzer for automated transport of specimens from the workstation to the analyzer.

20. The system of claim 19, wherein the workstation has an adjustment mechanism for aligning the delivery and receiving site with the robotic arm without moving either the analyzer or the workstation.

21. An analyzer for automated analysis of specimens in containers comprising:

(a) a base having opposed sides, a front, a top, and a back, the top having analytical equipment thereon and being accessible from the front by a user;

(b) a pedestal on the top of the base, the pedestal having a front work area and a roof; and

(c) a transport mechanism for automated transport of specimens from the workstation to the analyzer, the transport mechanism being on top of the roof.

22. A decapper system for removing pressed-in caps from specimen containers, comprising:

(a) a receiver for clampingly holding a container;

(b) a yoke member movably mounted relative to the receiver and having means for holding a cap seated in the container; and

(c) a translator for laterally moving the yoke member between open and closed positions thereof;

(d) an elevator for raising the yoke member, in the closed position thereof, relative to the receiver to thereby remove the cap;

(e) a collector for receiving caps from the yoke member; and

(f) an unloader for transfering removed caps from the yoke member to the collector.

23. The decapper system of claim 22, for use with each cap having a shoulder surface extending outwardly from opposite sides an adhacent container portion, wherein the holding means comprises the yoke having an upwardly facing ledge

portion for engaging the shoulder surface of a cap seated in the container, the ledge portion extending under the shoulder surface of the cap in the closed position

24. The decapper system of claim 22, further comprising a cap sensor for sensing and signaling passage of removed caps into the collector.

25. The decapper system of claim 22, further comprising a drive for rotating the receiver, for removal of threaded caps from the container.

26. The decapper system of claim 22, 23, 24, or 25, wherein the receiver comprises:

(a) a flexible sleeve within a rigid member for enclosing a bottom portion of the container, the sleeve having a closed end;

(b) a jaw member extending between the rigid member and the flexible sleeve; and

(c) an actuator for moving the jaw member forceably against the sleeve, thereby the clamp the container relative to the rigid member.

27. A method for automatically processing multiple containers containing specimens, at least some of the containers having a cap, each of the containers having container identification indicia thereon, the containers being held in a holder, the method comprising the steps of:

(a) providing a controller having memory for holding processing instructions for the processing of each container according to the container identification indicia;

(b) detecting the presence of a holder in the system and signaling the presence of a holder to the controller;

(c) reading the container identification indicia and signaling the container identification indicia to the controller;

(d) selectively transporting the containers by a robotic arm into a plurality of sort sites according to corresponding processing instructions associated with the respective container indicia;

(e) centrifuging selected specimens by the steps of:

(i) selectively transporting and loading the containers into multiple centrifuge receptacles by the robotic arm according to the corresponding processing instructions;

(ii) balancing the weight of the loaded receptacles;

(iii) placing balanced receptacles in a centrifuge by the robotic arm;

(iv) simultaneously centrifuging multiple receptacles in response to instructions from the controller,

(v) unloading the centrifuge by stopping the centrifuge, indexing the centrifuge to selected unloading positions, and removing receptacles from the centrifuge by the robotic arm in response to signals from the controller;

(f) selectively decapping centrifuged containers by transporting centrifuged containers to a decapper with the robotic arm and decapping; and

(g) selectively analyzing the specimens by transporting selected containers to an analyzer in accordance with instructions from the controller and analyzing the specimens with the analyzer, and reporting the analysis results to the controller.

28. A method for automatically processing multiple containers containing specimens, each of the containers having container identification indicia thereon, the containers being held in a holder, the method comprising the steps of:

(a) storing in a memory storage of a controller, processing instructions for the processing of each container according to the container identification indicia;

(b) automatically detecting the presence of a holder in the system and signalling the presence of a holder to the controller;

(c) reading the container identification indicia and signalling the container identification indicia to the controller; and

(d) selectively transporting the containers with a robotic arm to a plurality of sort sites according to their processing instructions.

29. A method for automatically processing multiple containers containing specimens, each of the containers having container identification indicia thereon, the containers being held in a holder, the method comprising the steps of:

(a) storing in a memory storage of a controller processing instructions for the processing of each container according to the container identification indicia;

(b) reading the container identification indicia and signaling the container identification indicia to the controller; and

(c) centrifuging selected specimens by the steps of:

(i) selectively transporting the containers to multiple centrifuge receptacles and loading the receptacles by a robotic arm according to processing instructions from the controller;

(ii) balancing the receptacles;

(iii) placing balanced receptacles in a centrifuge with the robotic arm, the centrifuge having a lid with a closed position and an open position;

(iv) simultaneously centrifuging multiple receptacles in response to instructions from the controller, and

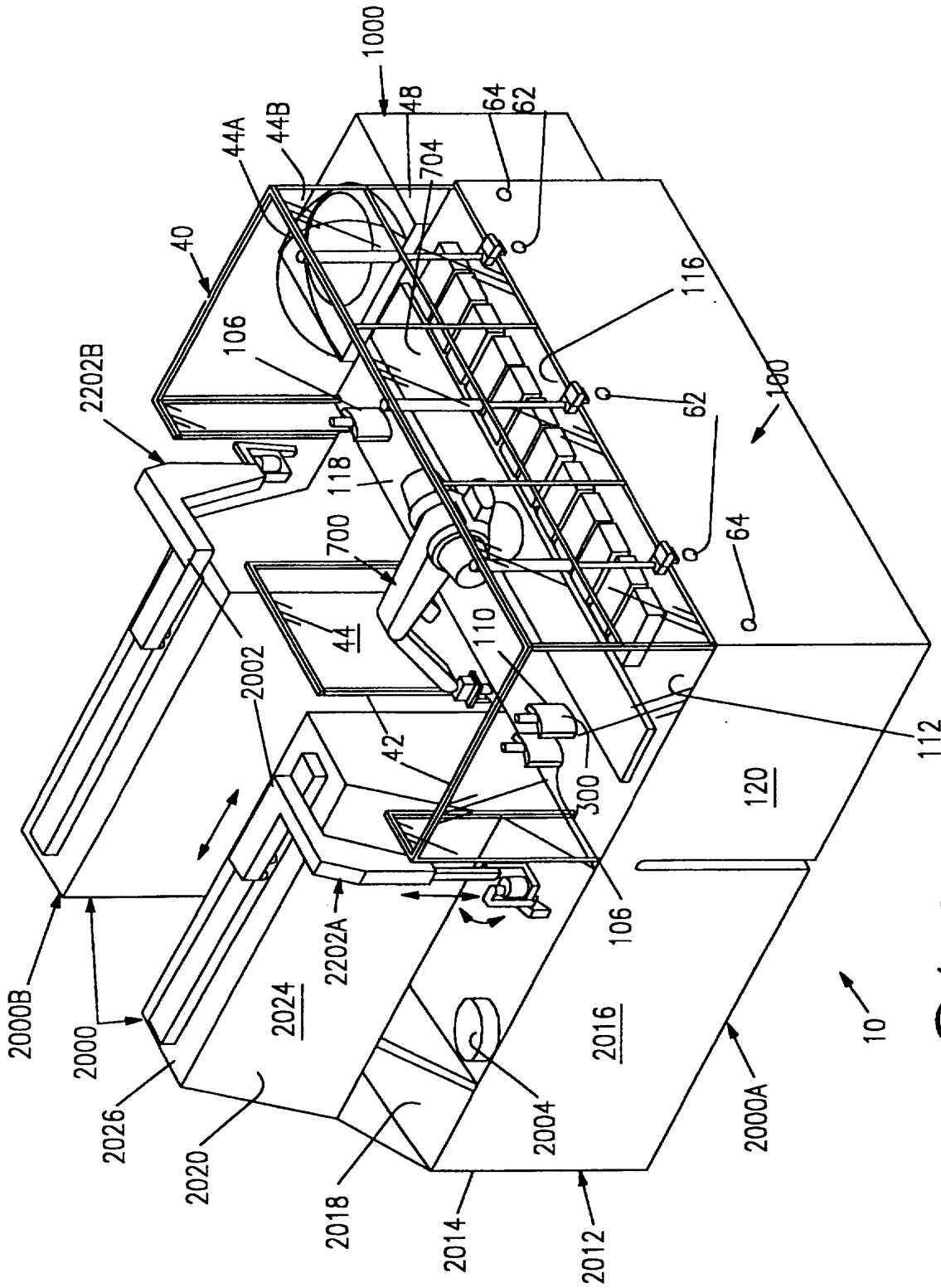
(v) unloading the centrifuge by stopping the centrifuge, opening the lid, indexing the centrifuge to selected unloading positions, and removing receptacles from the centrifuge with the robotic arm in response to signals from the controller.

30. The method of claim 27 or 29, wherein the balancing step comprises:

(a) monitoring the total weight of the receptacles and particular receptacles loaded as each container is loaded therein;

(b) determining, from successive load increments and receptacles loaded, a loading of each receptacle; and

(c) adjusting the loading of particular receptacle pairs to achieve a predetermined degree of balance.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44A
44B
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40
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62
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118
700
64
44
110
2002
42
112
300
120
106
2202A
2000B
2000
2024
2016
2026
2020
2004
2000A
2018
2014
2012
10

Fig. 1

SYSTEM OVERVIEW

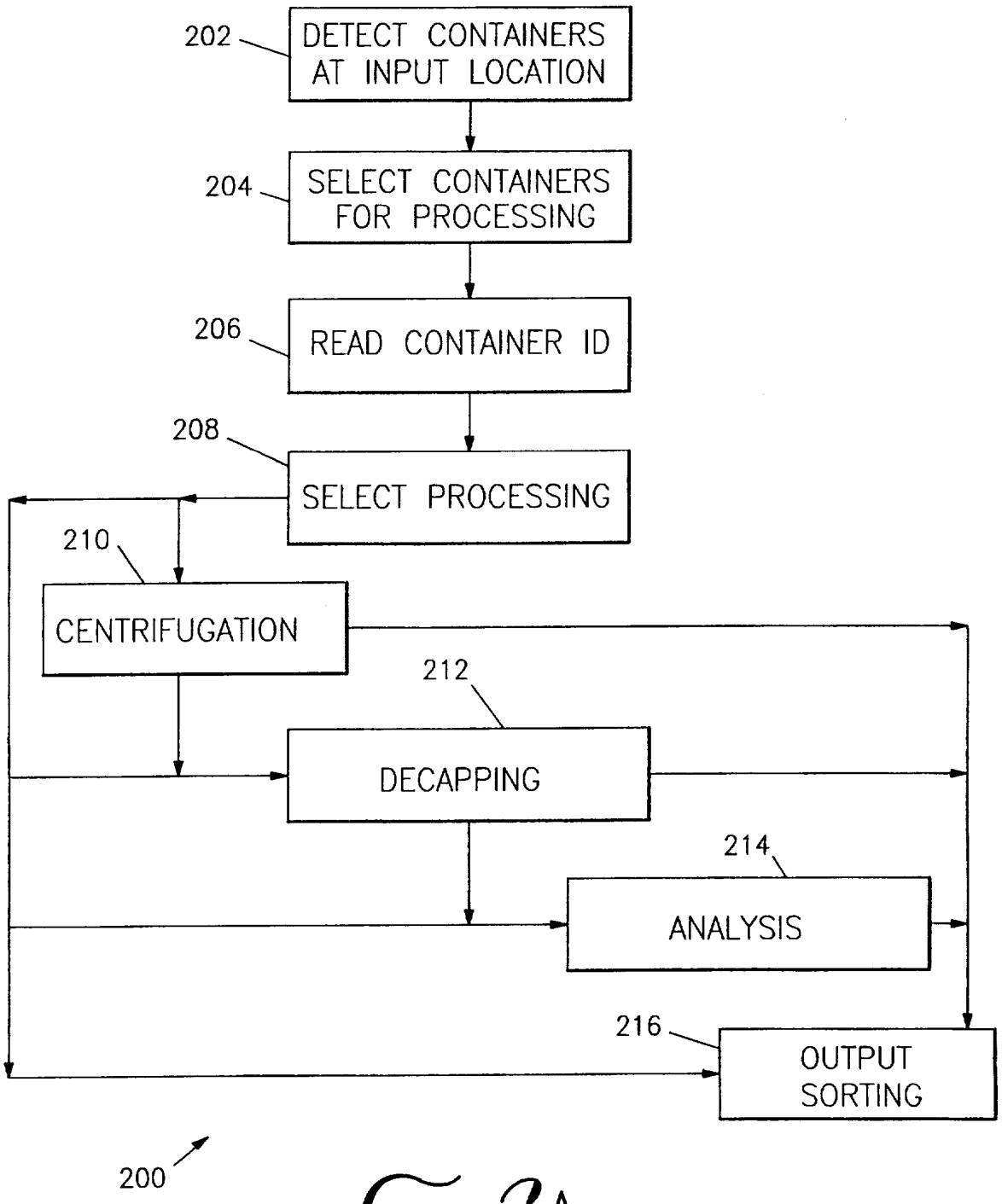

FIG. 2A

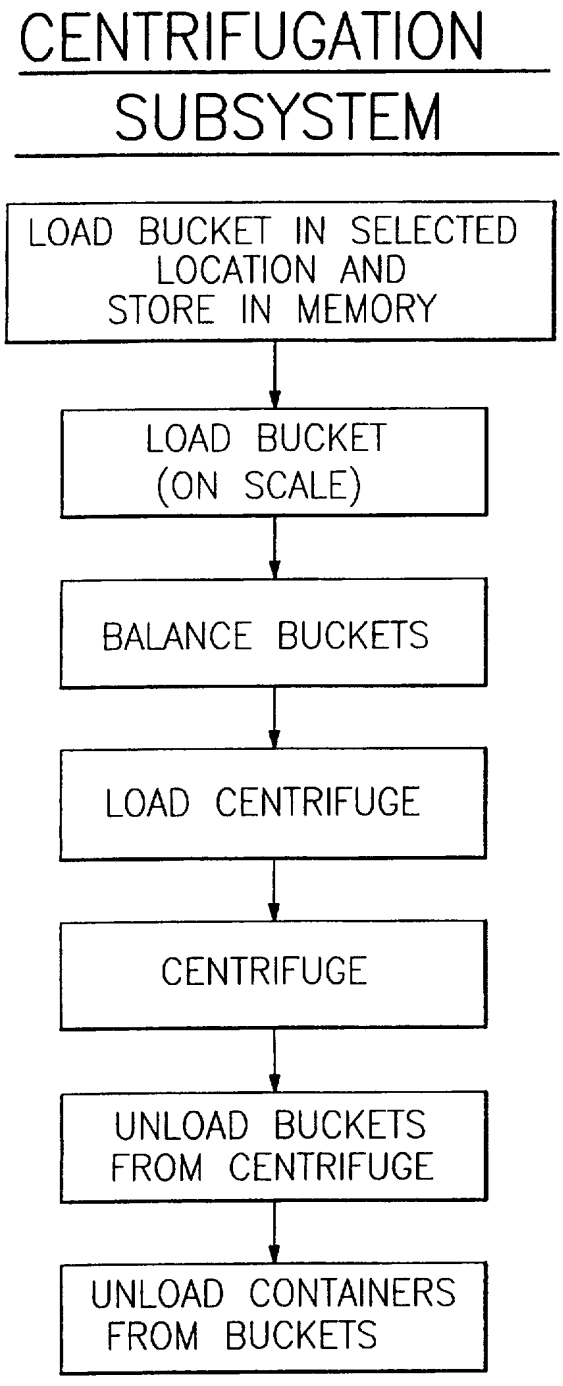
CENTRIFUGATION SUBSYSTEM
LOAD BUCKET IN SELECTED LOCATION AND STORE IN MEMORY
LOAD BUCKET (ON SCALE)
BALANCE BUCKETS
LOAD CENTRIFUGE
CENTRIFUGE
UNLOAD BUCKETS FROM CENTRIFUGE
UNLOAD CONTAINERS FROM BUCKETS
210

FIG. 2B

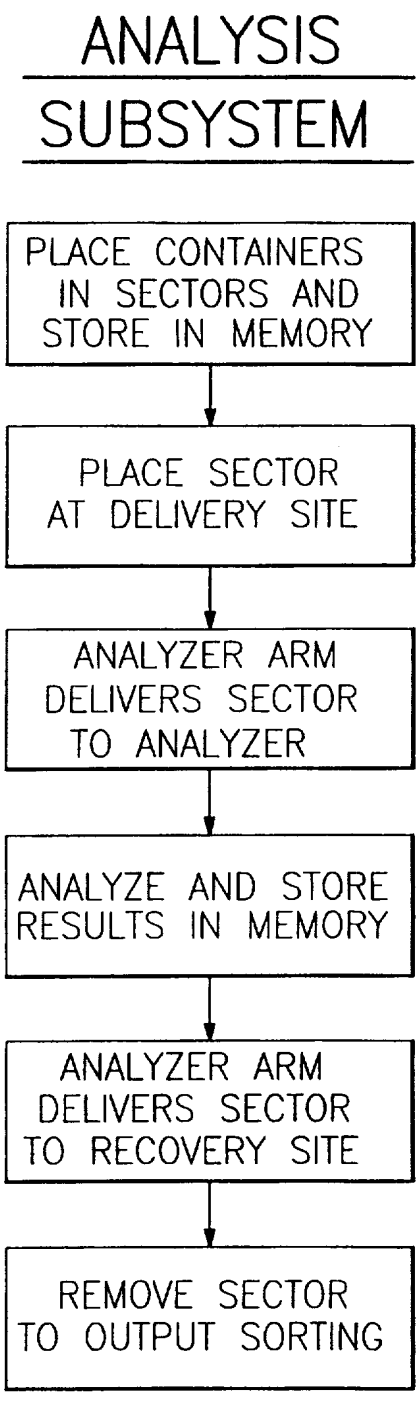
ANALYSIS SUBSYSTEM
PLACE CONTAINERS IN SECTORS AND STORE IN MEMORY
PLACE SECTOR AT DELIVERY SITE
ANALYZER ARM DELIVERS SECTOR TO ANALYZER
ANALYZE AND STORE RESULTS IN MEMORY
ANALYZER ARM DELIVERS SECTOR TO RECOVERY SITE
REMOVE SECTOR TO OUTPUT SORTING
214

FIG. 2C

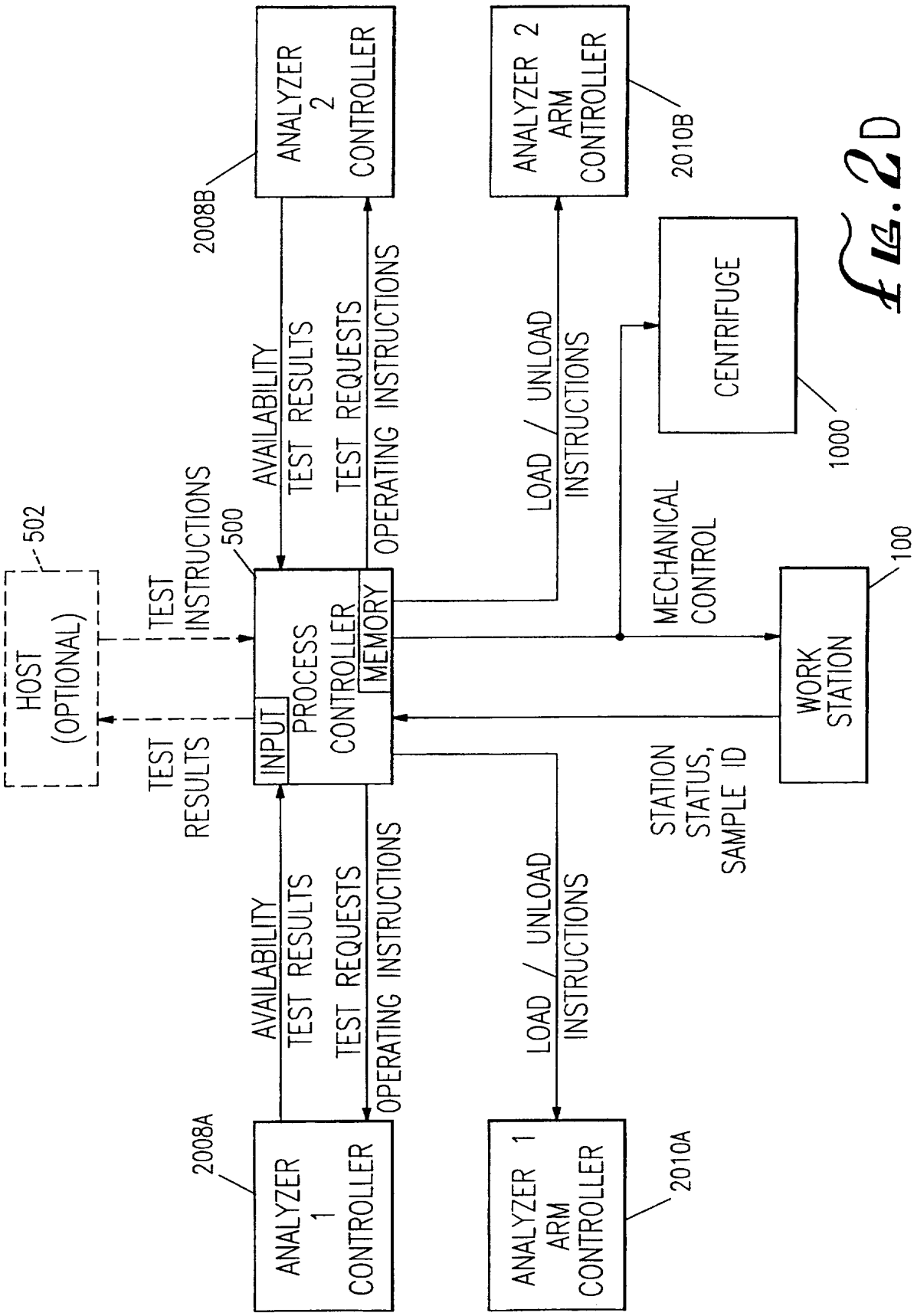
HOST (OPTIONAL)
502
TEST INSTRUCTIONS
TEST RESULTS
500
INPUT
PROCESS CONTROLLER
MEMORY
AVAILABILITY
TEST RESULTS
TEST REQUESTS
OPERATING INSTRUCTIONS
2008B
ANALYZER 2 CONTROLLER
2008A
ANALYZER 1 CONTROLLER
LOAD / UNLOAD INSTRUCTIONS
ANALYZER 2 ARM CONTROLLER
2010B
ANALYZER 1 ARM CONTROLLER
2010A
MECHANICAL CONTROL
CENTRIFUGE
1000
STATION STATUS, SAMPLE ID
WORK STATION
100

Fig. 2D

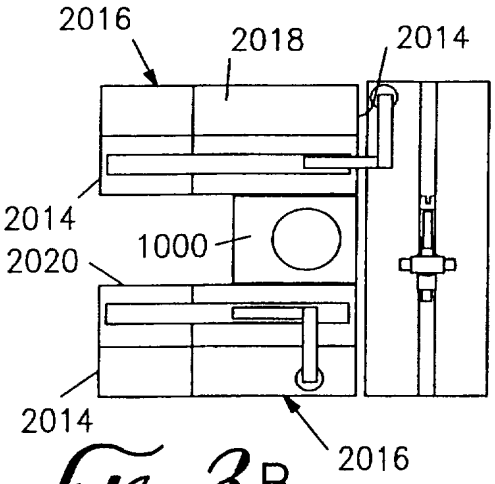

FIG. 3B

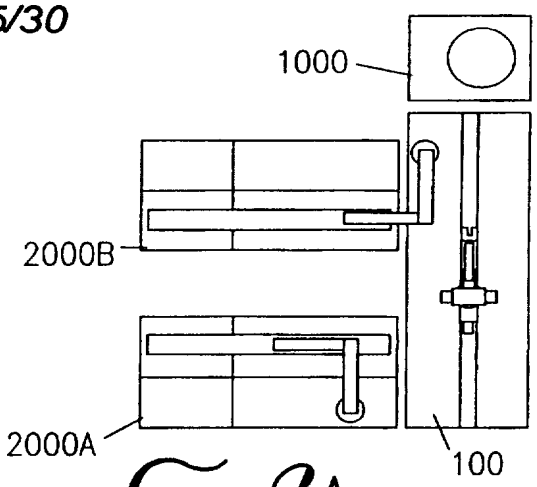

FIG. 3A

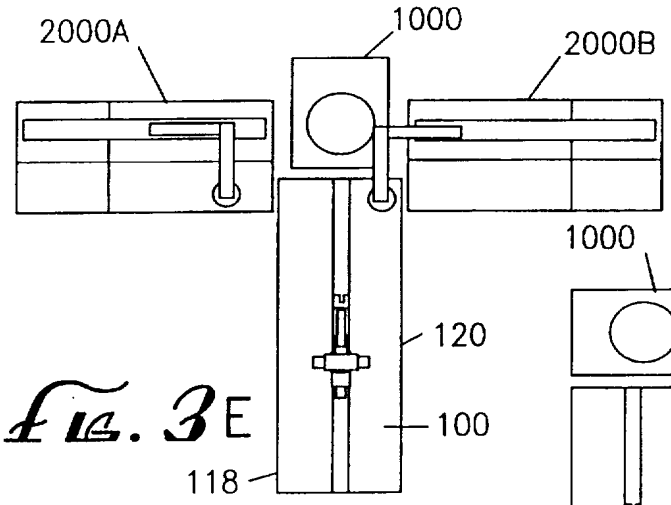

FIG. 3E

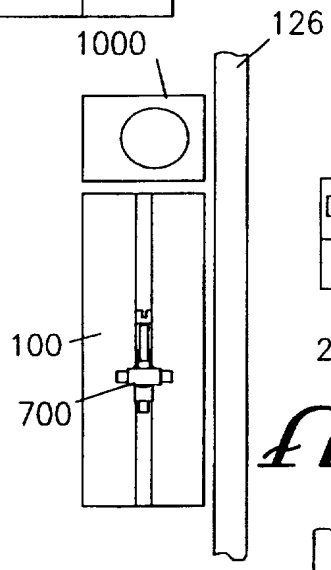

FIG. 3F

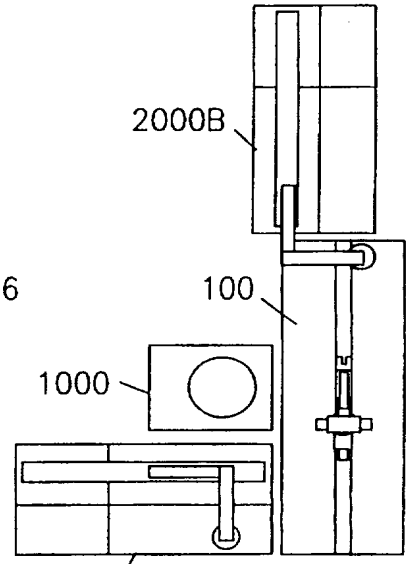

FIG. 3C

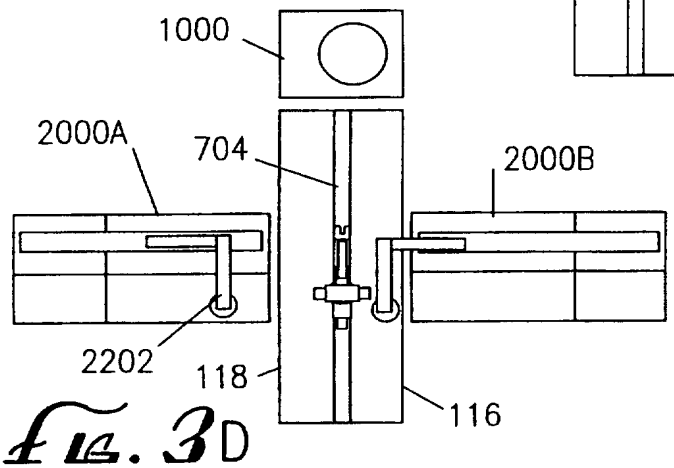

FIG. 3D

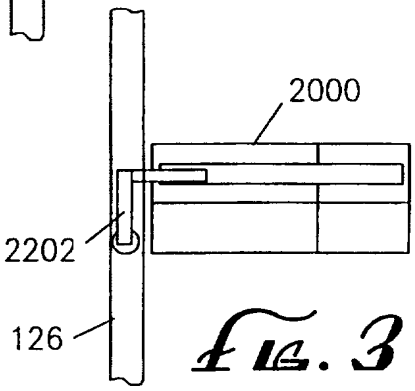

FIG. 3G

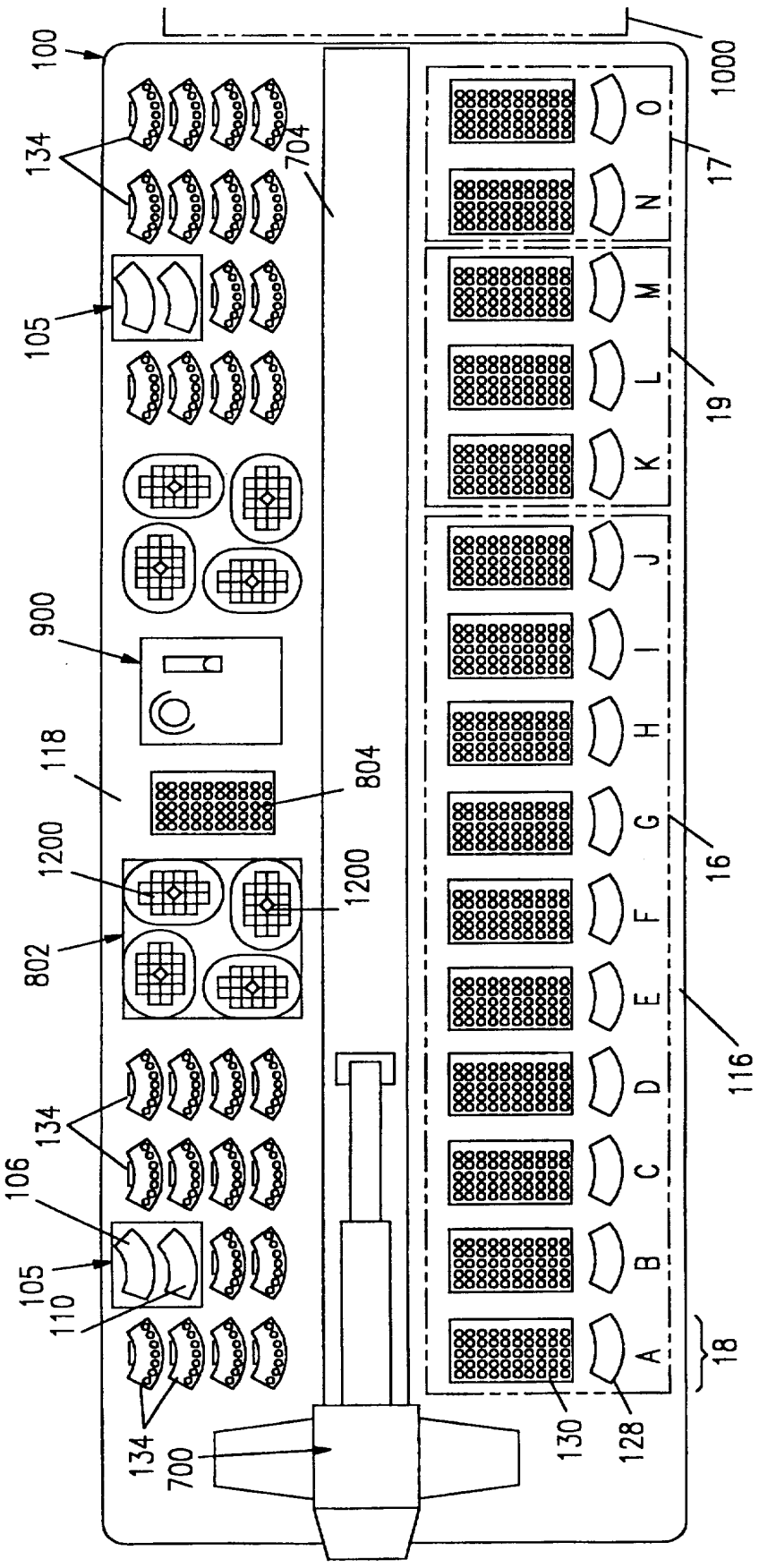
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FIG. 4

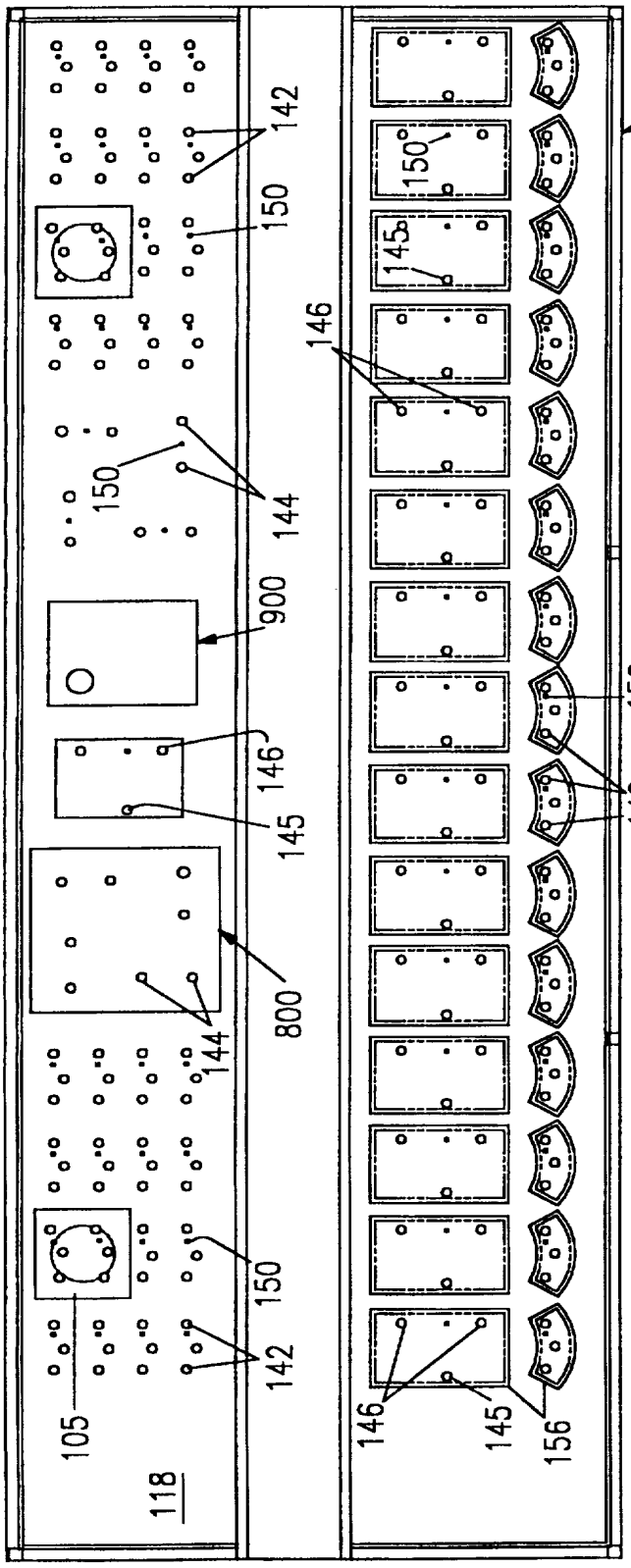

FIG. 5

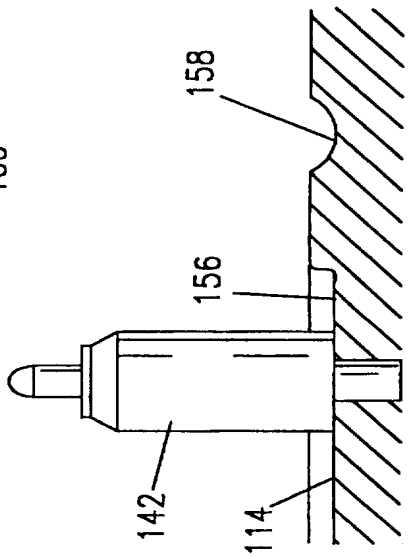

FIG. 6A

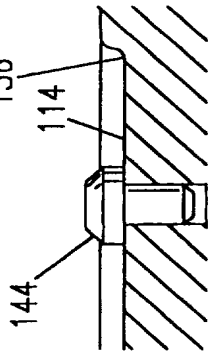

FIG. 6B

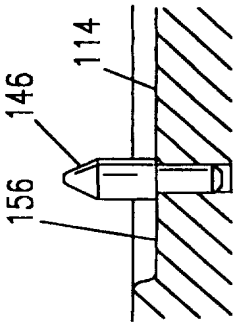

FIG. 6C

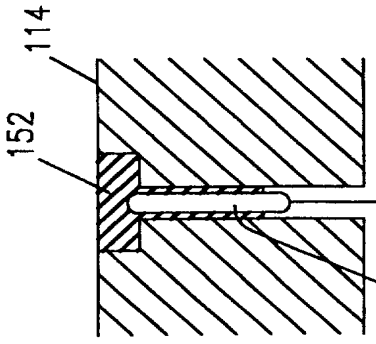

FIG. 7

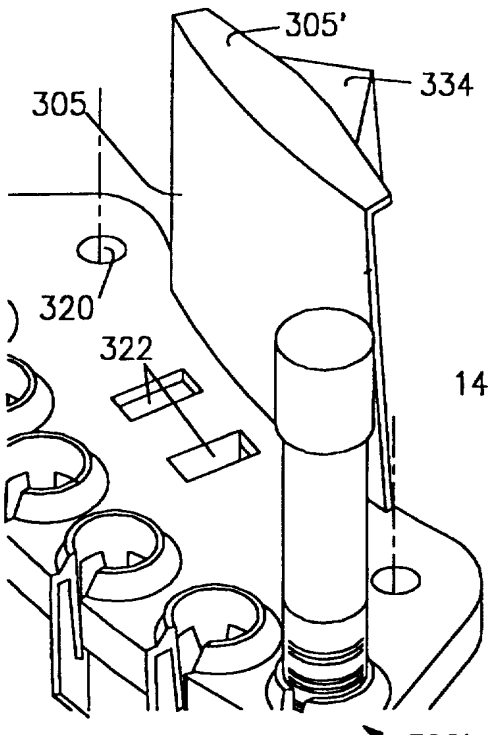

FIG. 8D

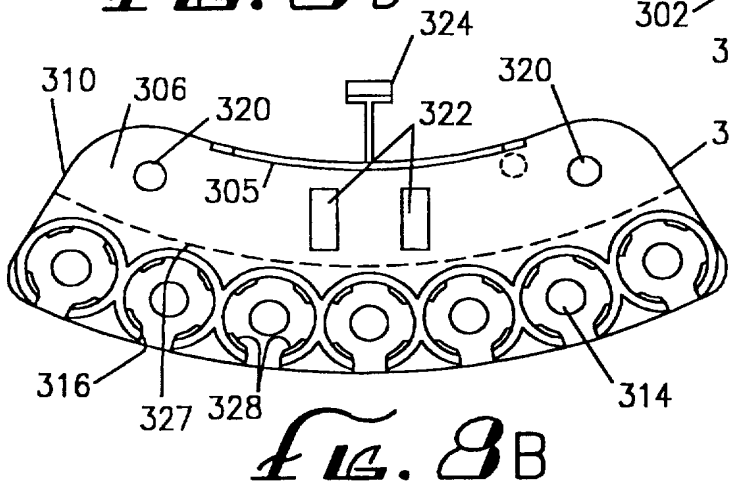

FIG. 8B

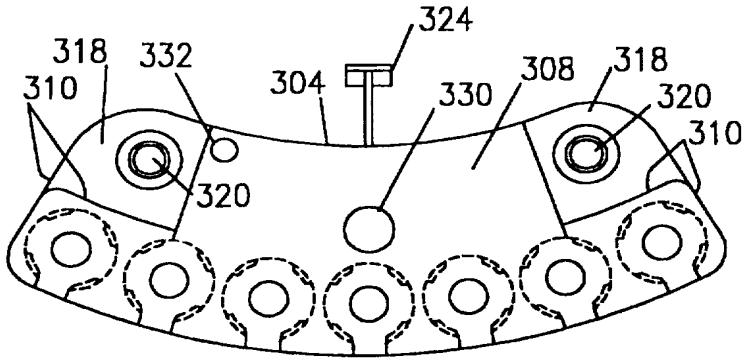

FIG. 8C

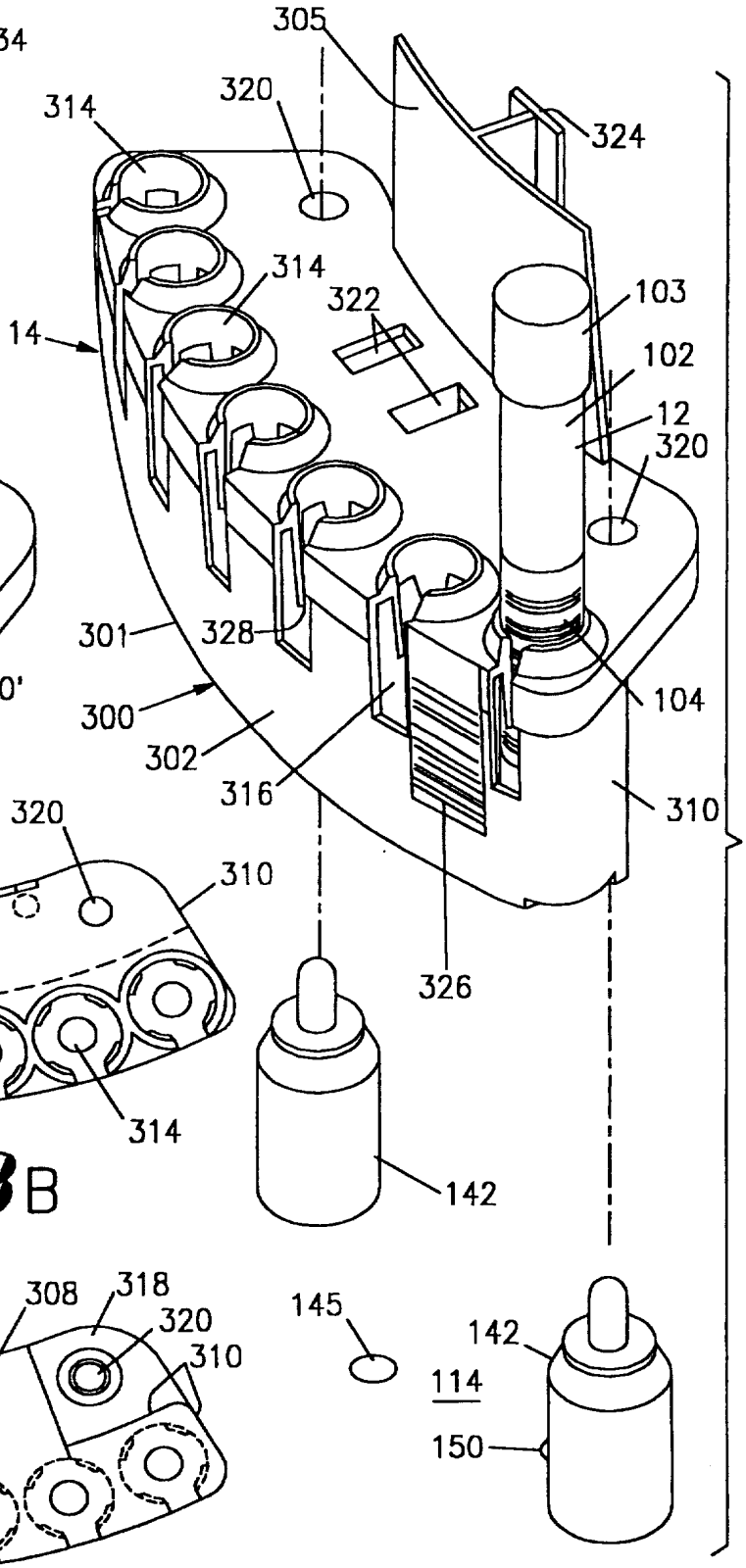

FIG. 8A

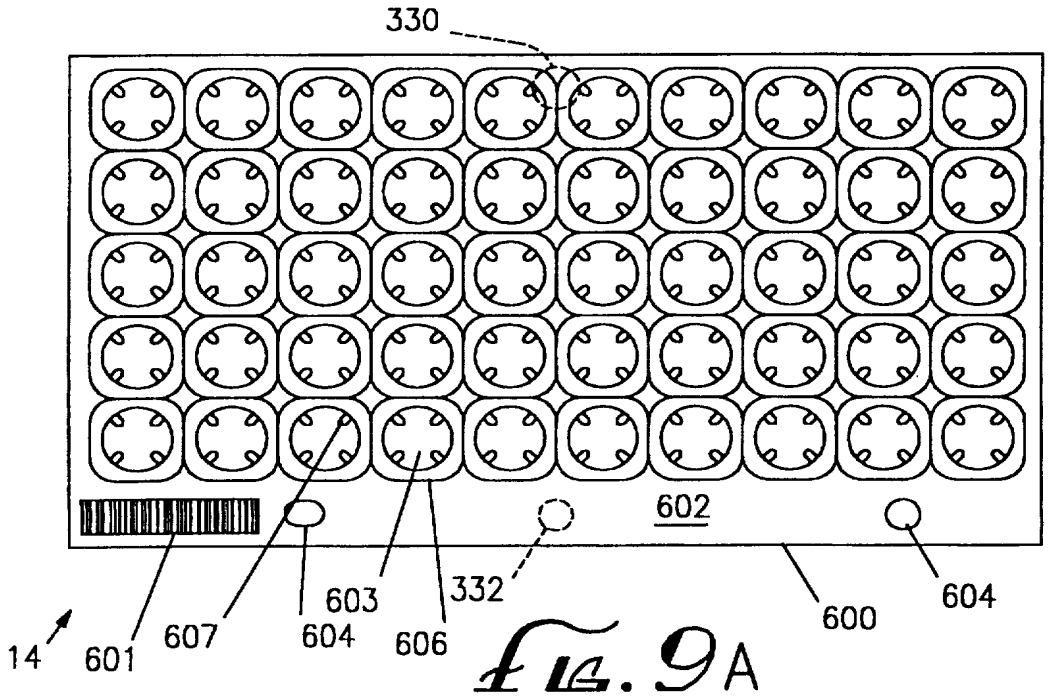

FIG. 9A

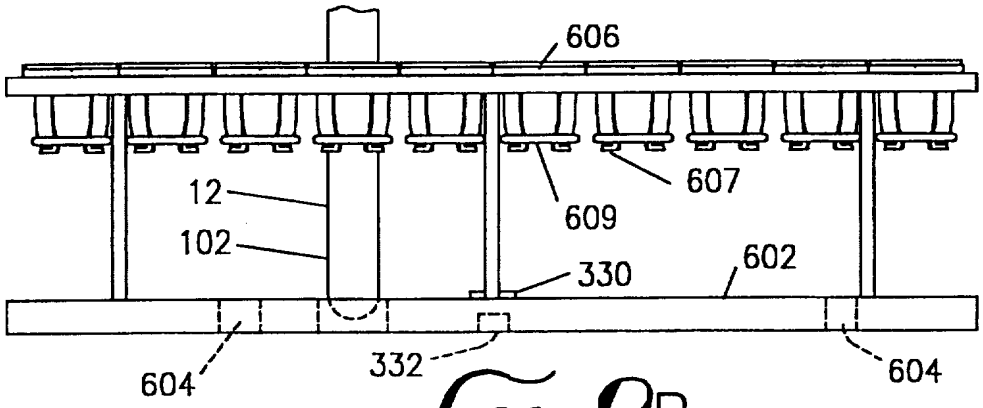

FIG. 9B

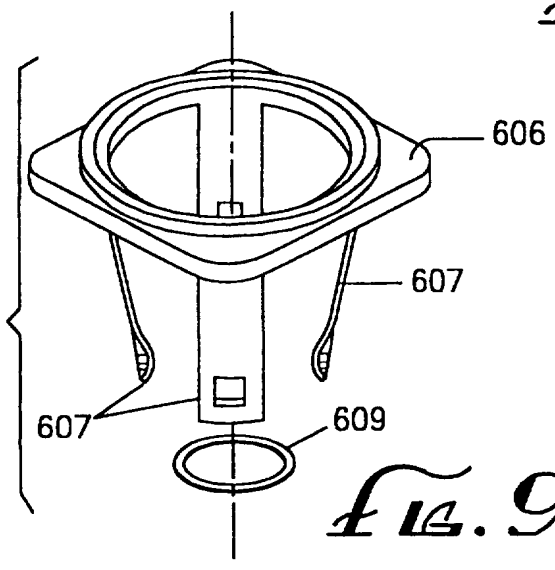

FIG. 9C

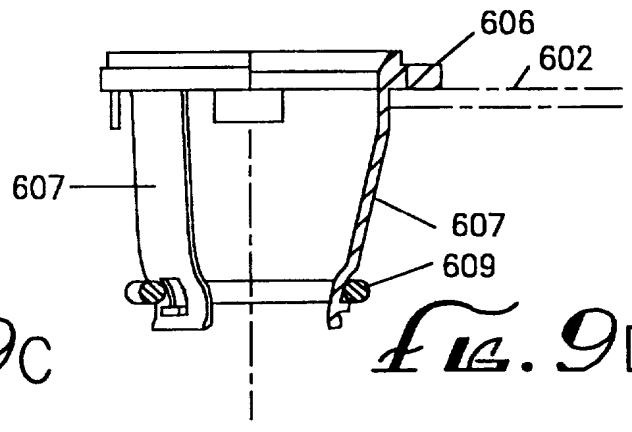

FIG. 9D

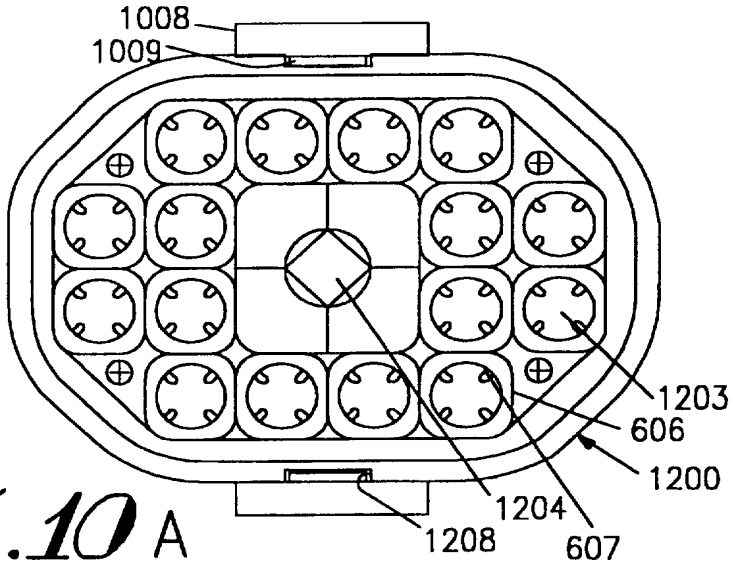

FIG. 10 A

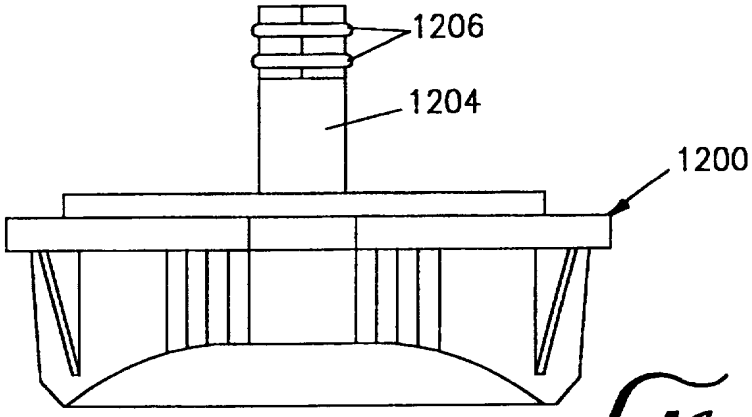

FIG. 10 B

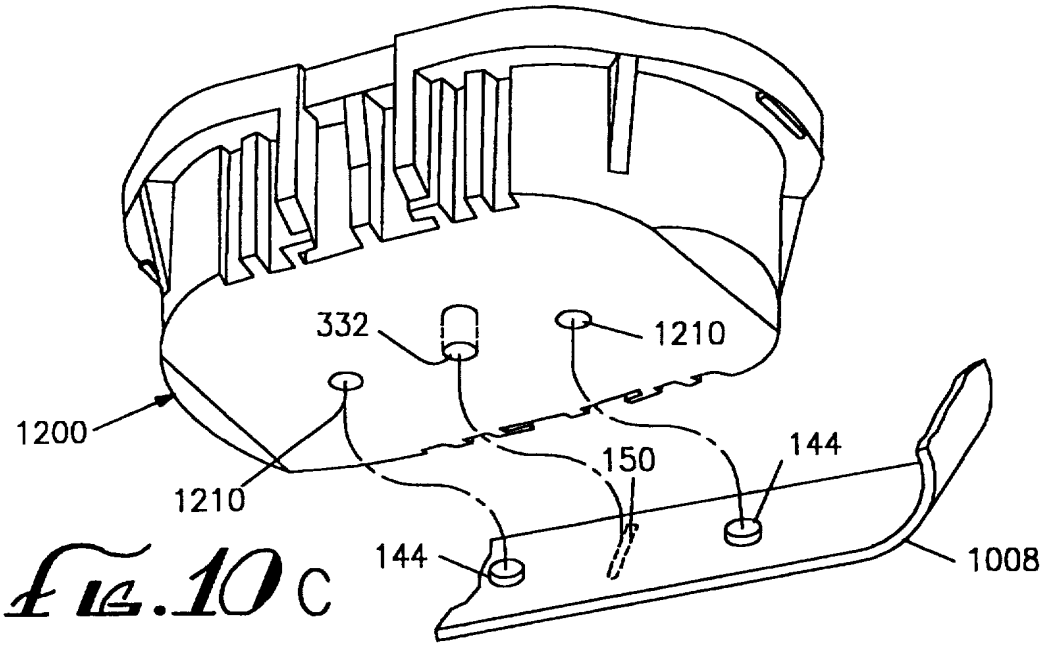

FIG. 10 C

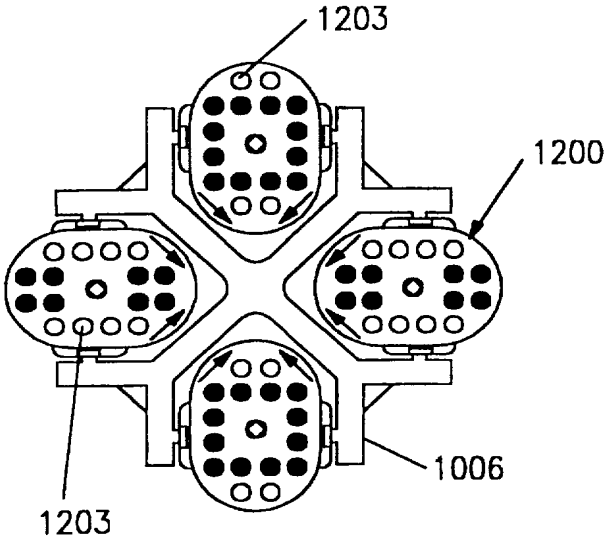

FIG. 11A

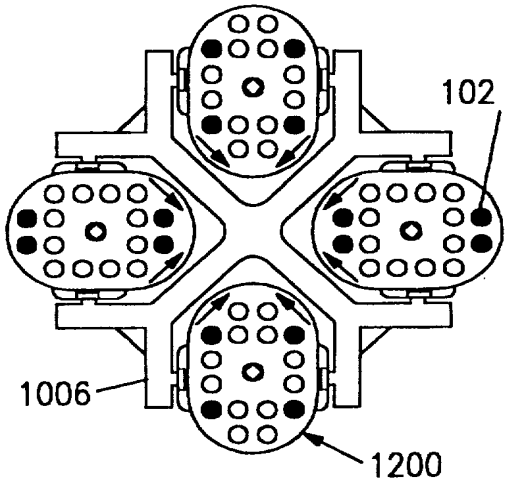

FIG. 11B

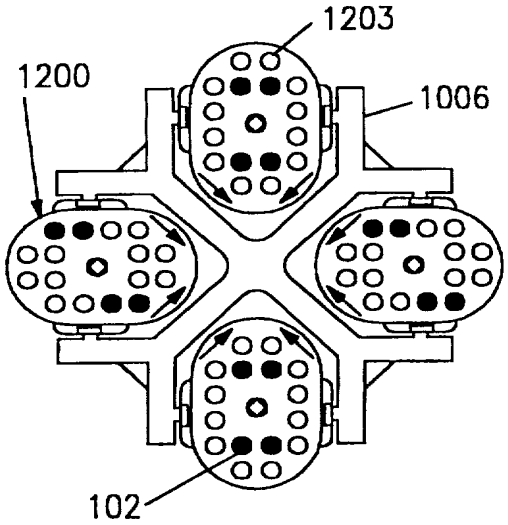

FIG. 11C

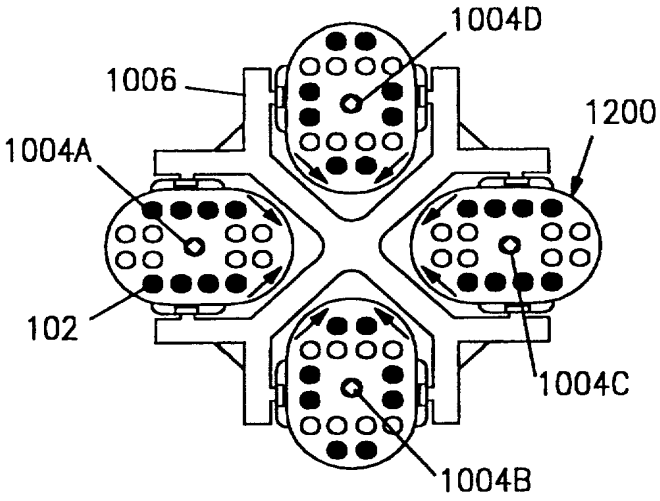

FIG. 11D

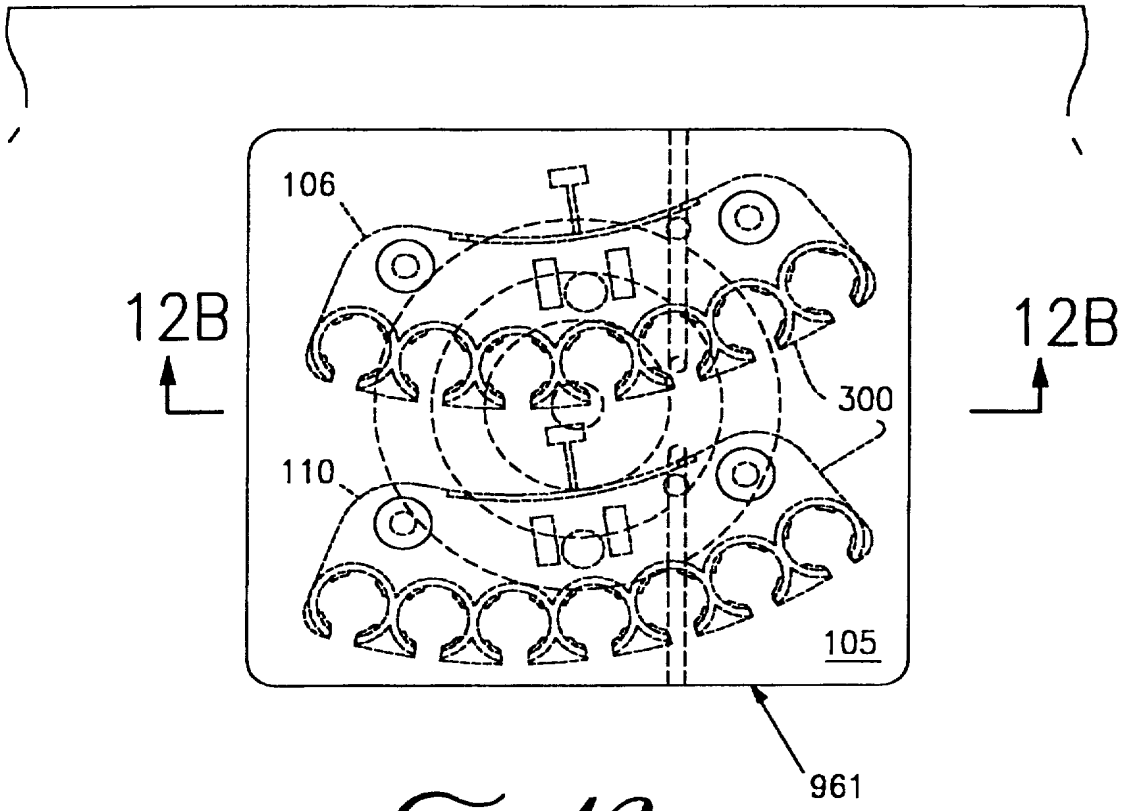

FIG. 12A

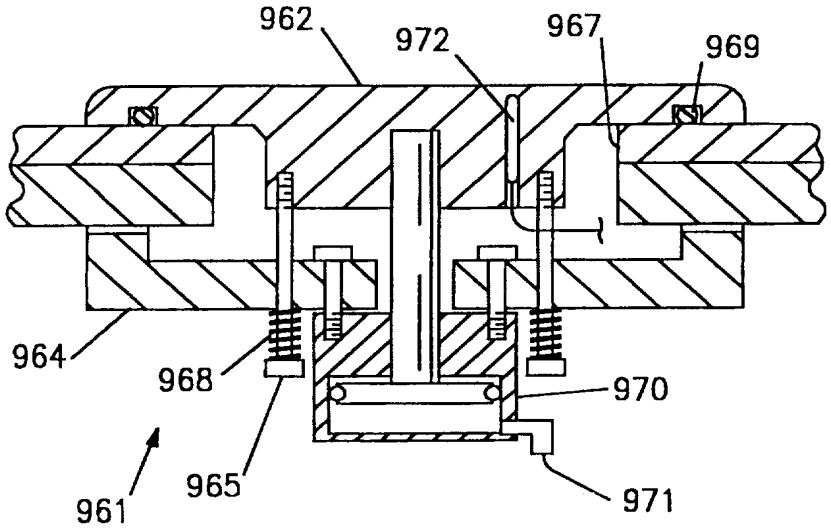

FIG. 12B

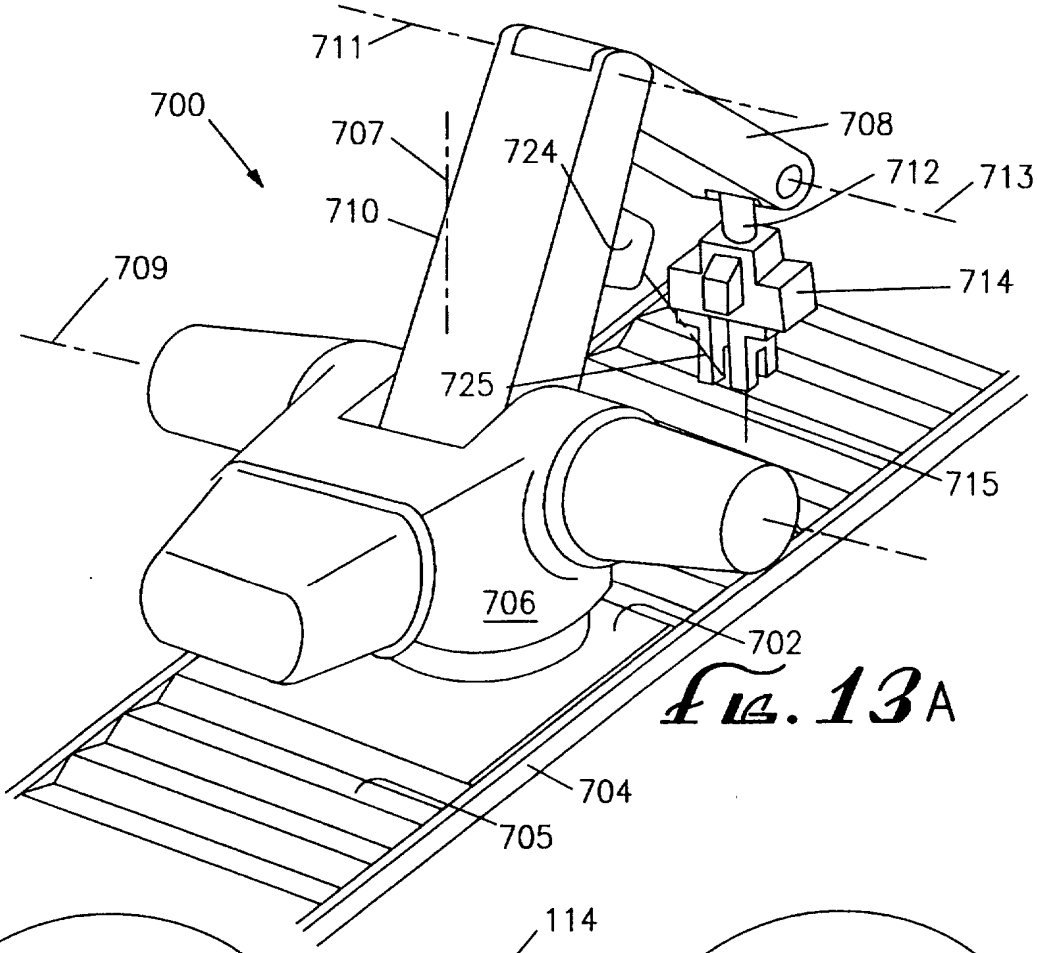

FIG. 13A

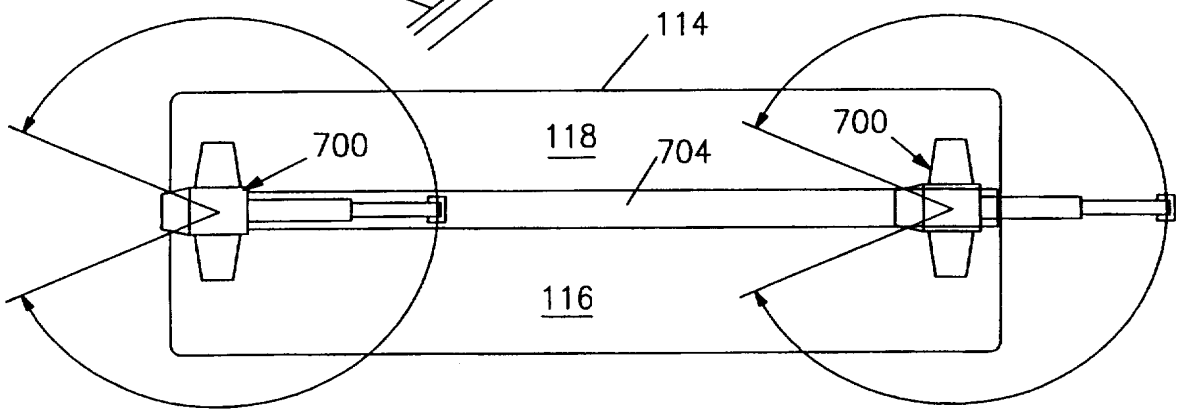

FIG. 13B

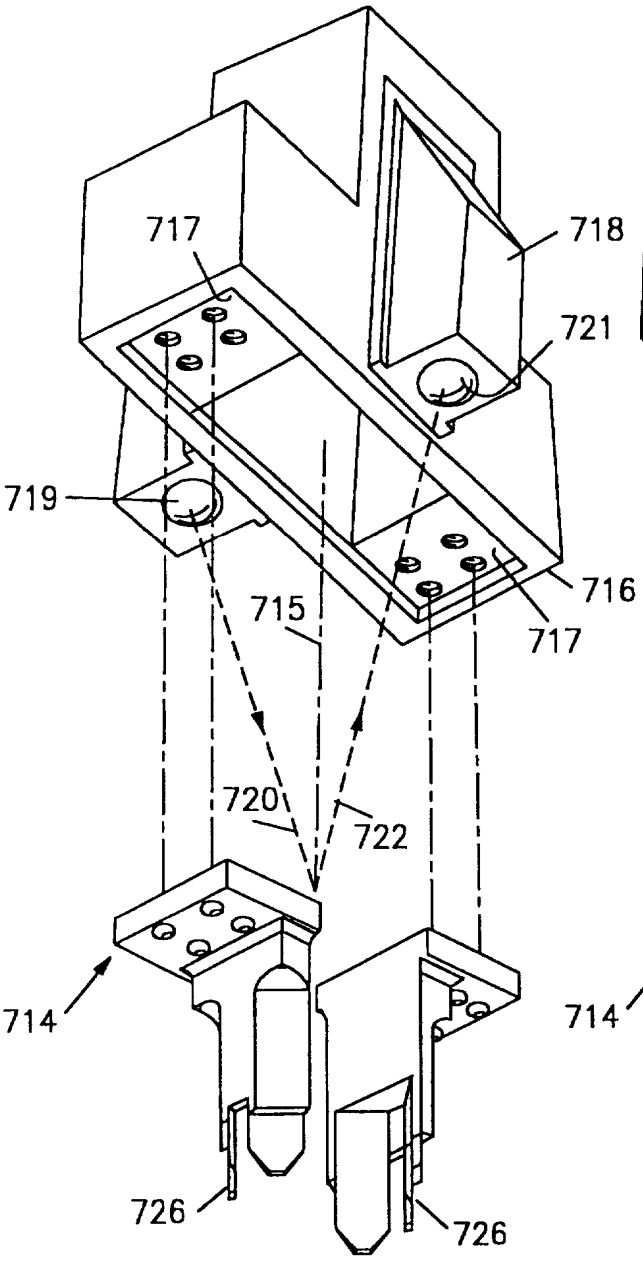

Fig. 13C

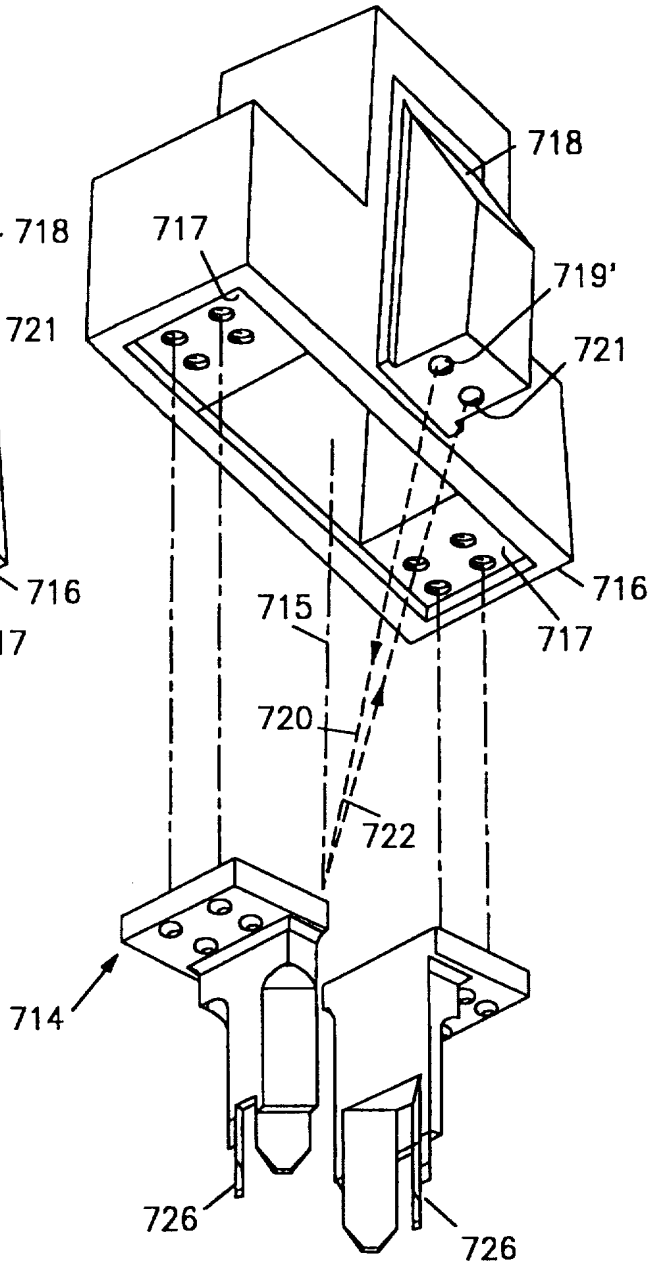

Fig. 13D

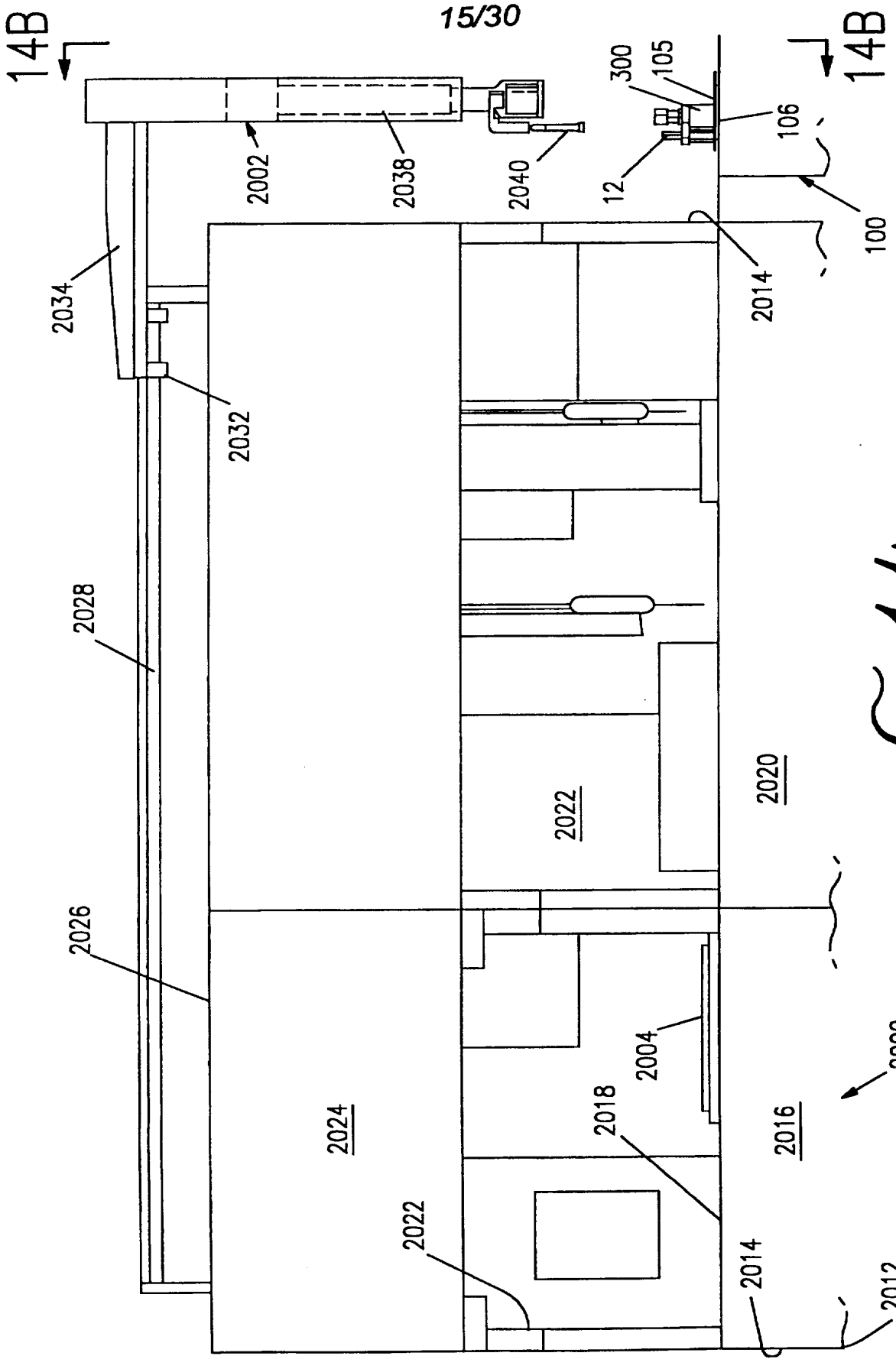
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FIG. 14A

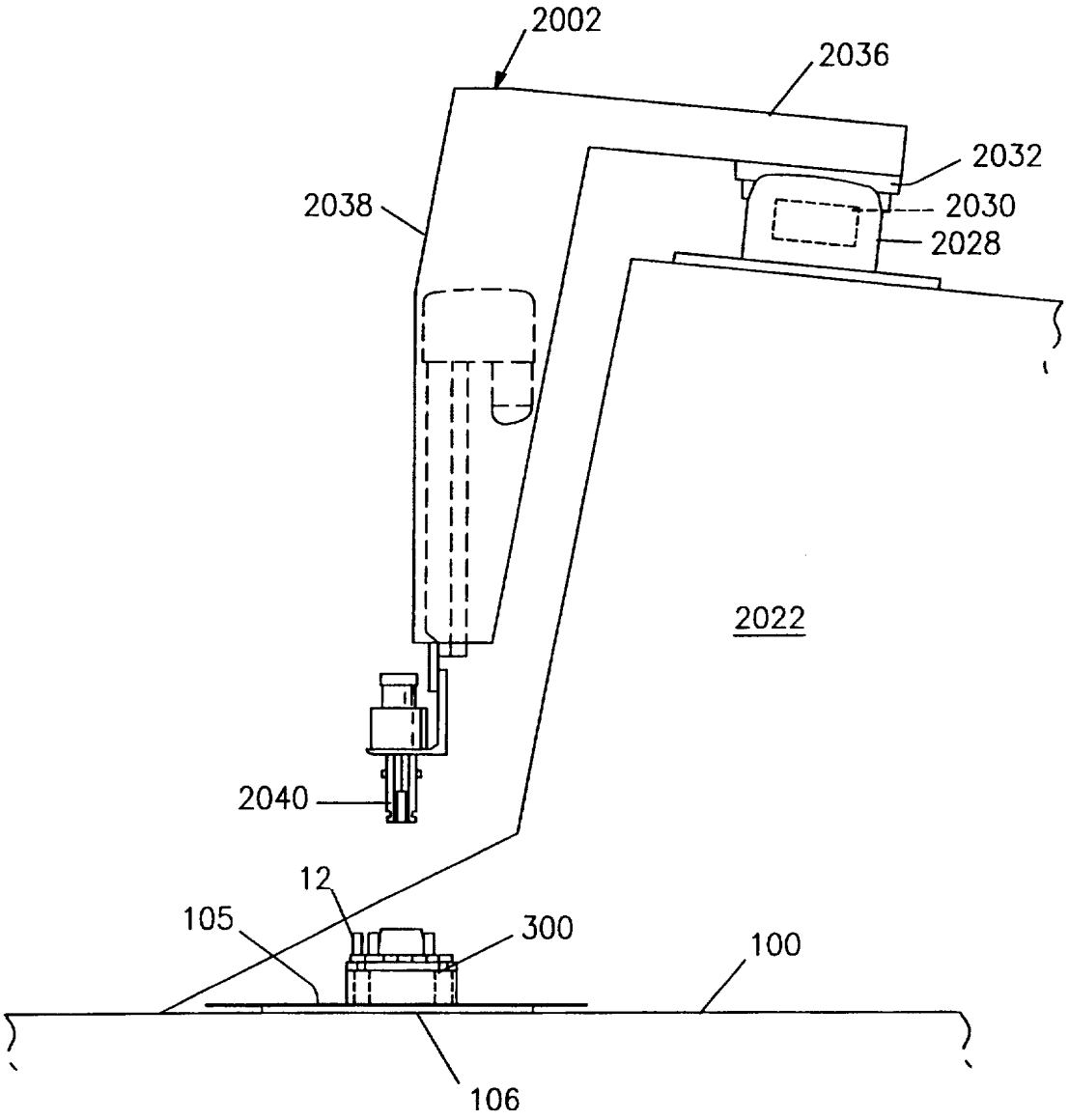


FIG. 14B

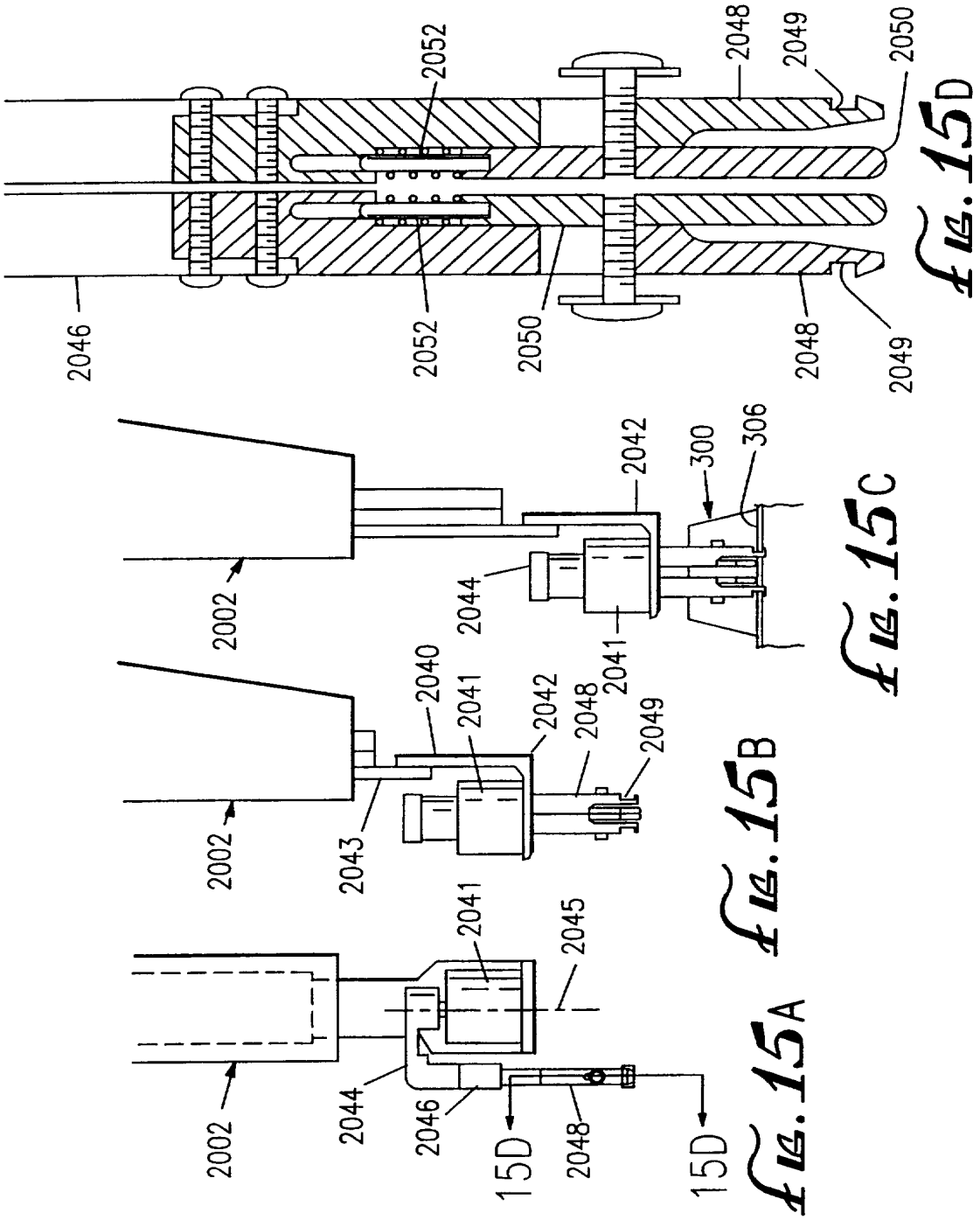


Fig. 15D

Fig. 15C

Fig. 15B

Fig. 15A

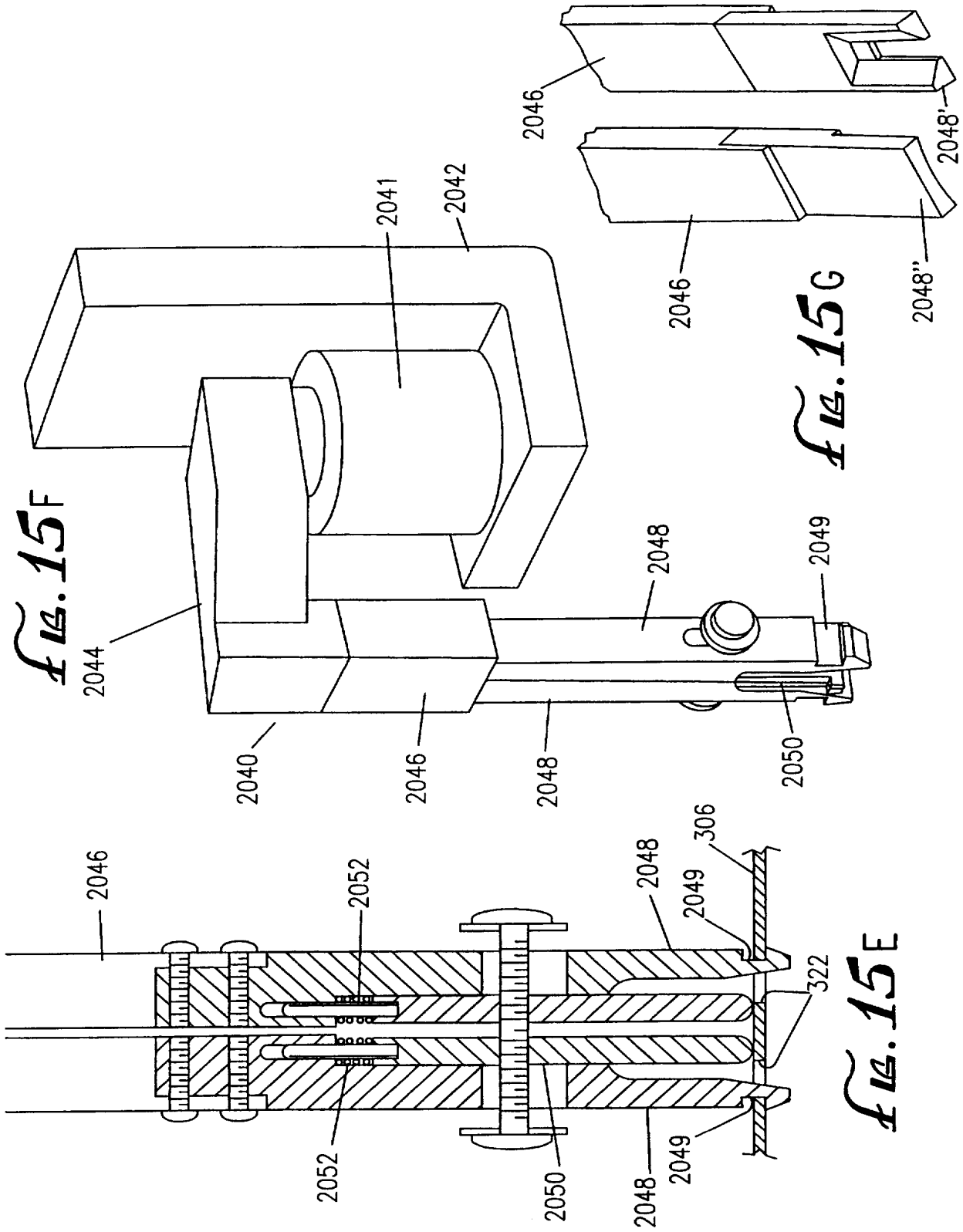
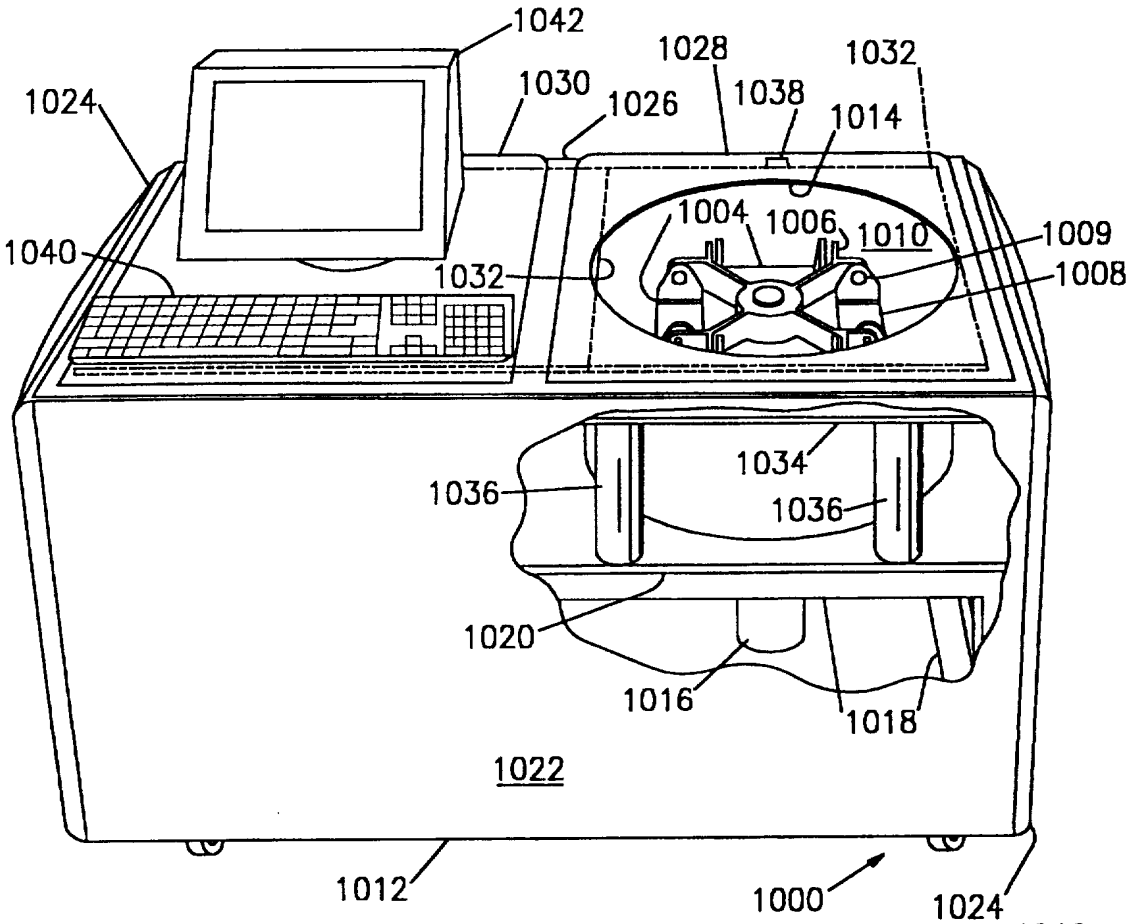


Fig. 15G

Fig. 15F

Fig. 15E

FIG. 16A



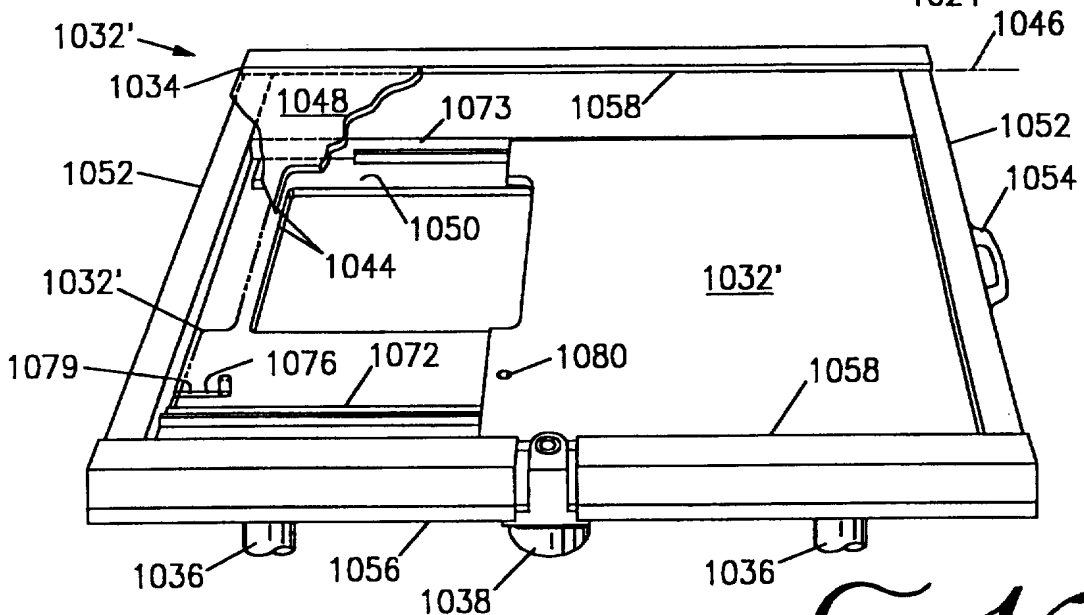


FIG. 16B

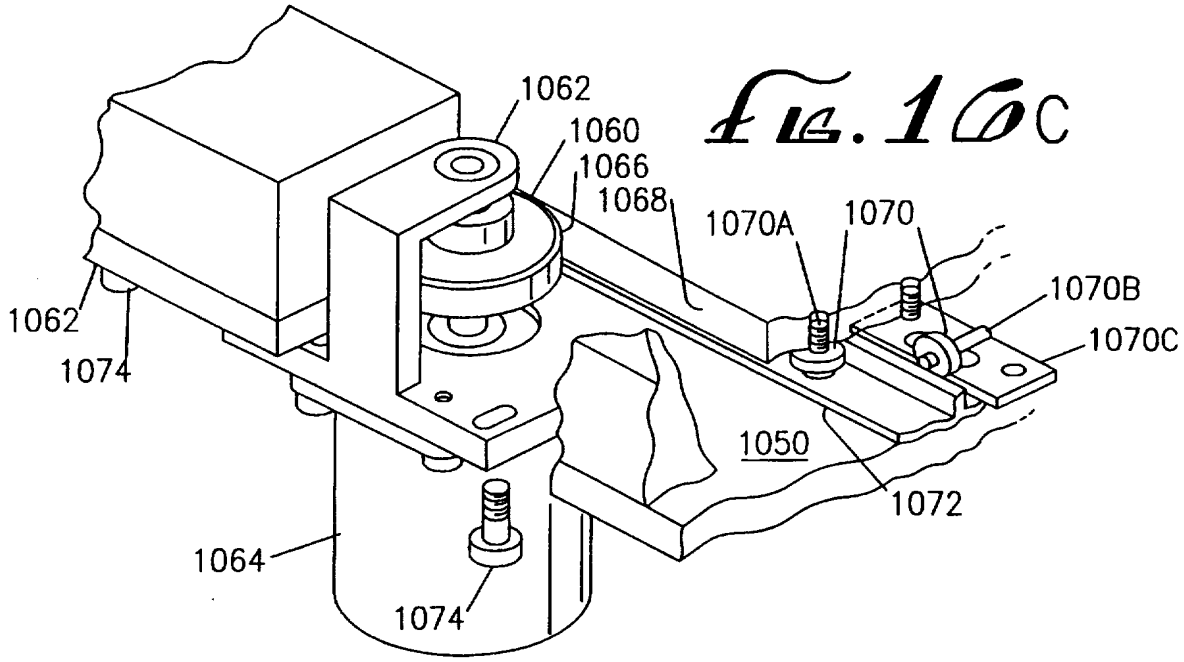


FIG. 16C

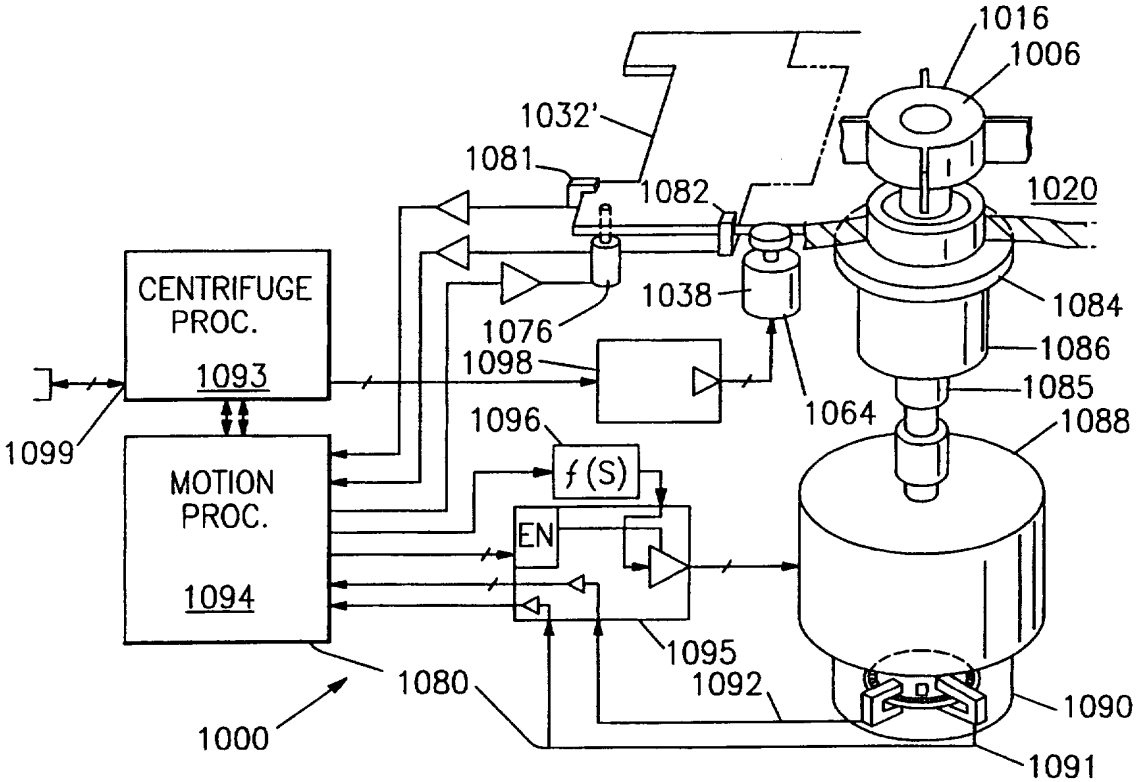


FIG. 16D

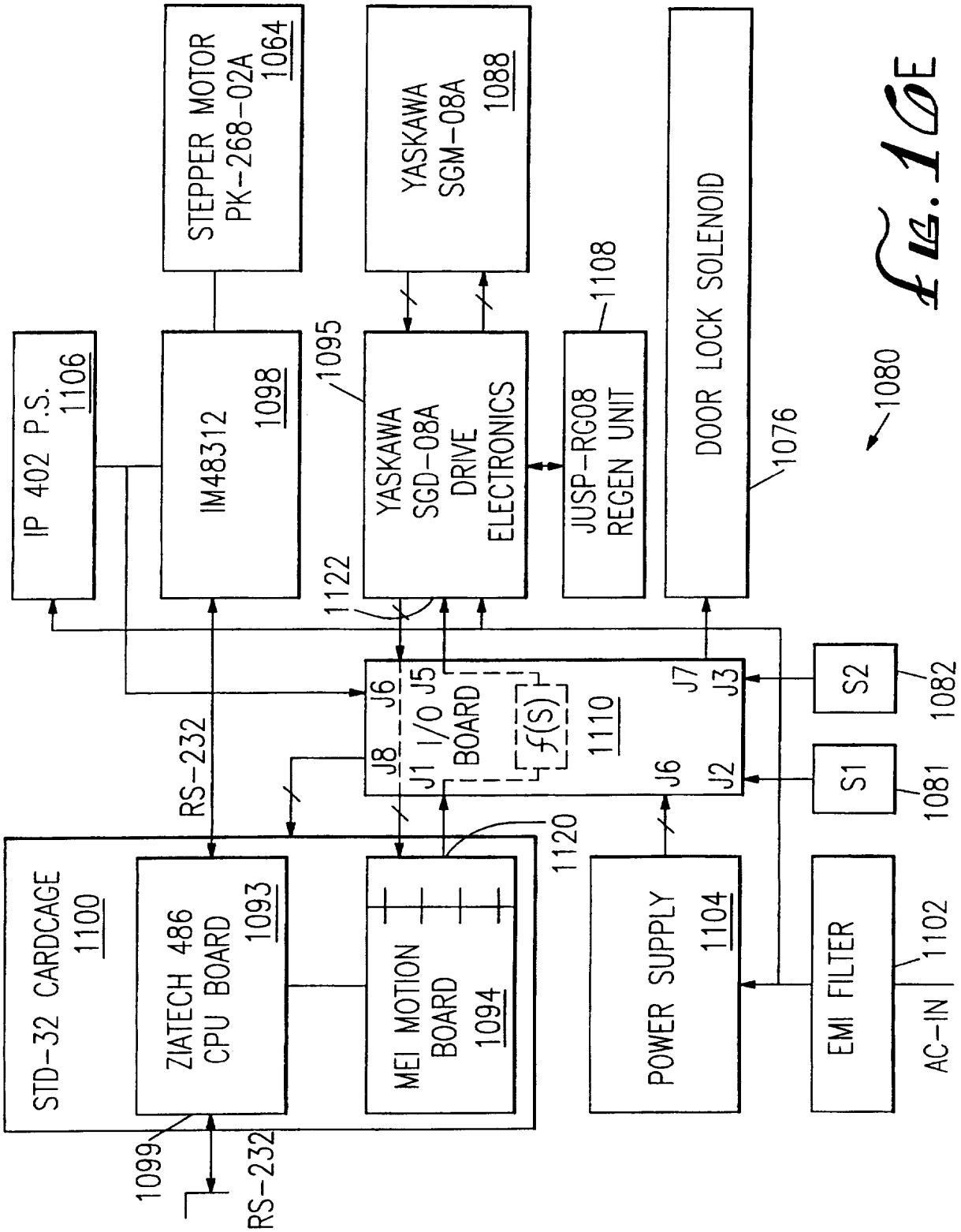

STEPPER MOTOR PK-268-02A 1064
YASKAWA SGM-08A 1088
IP 402 P.S. 1106
IM48312 1098
1095
YASKAWA SGD-08A DRIVE ELECTRONICS
1108
JUSP-RG08 REGEN UNIT
DOOR LOCK SOLENOID
1076
1080
1122
RS-232
J6
J5
J8
J1 I/O BOARD
f(S)
1110
J7
J3
J6
J2
S2
1082
S1
1081
1120
STD-32 CARDCAGE 1100
ZIATECH 486 CPU BOARD 1093
MEI MOTION BOARD 1094
POWER SUPPLY 1104
EMI FILTER
1102
AC-IN
1099
RS-232

Fig. 16E

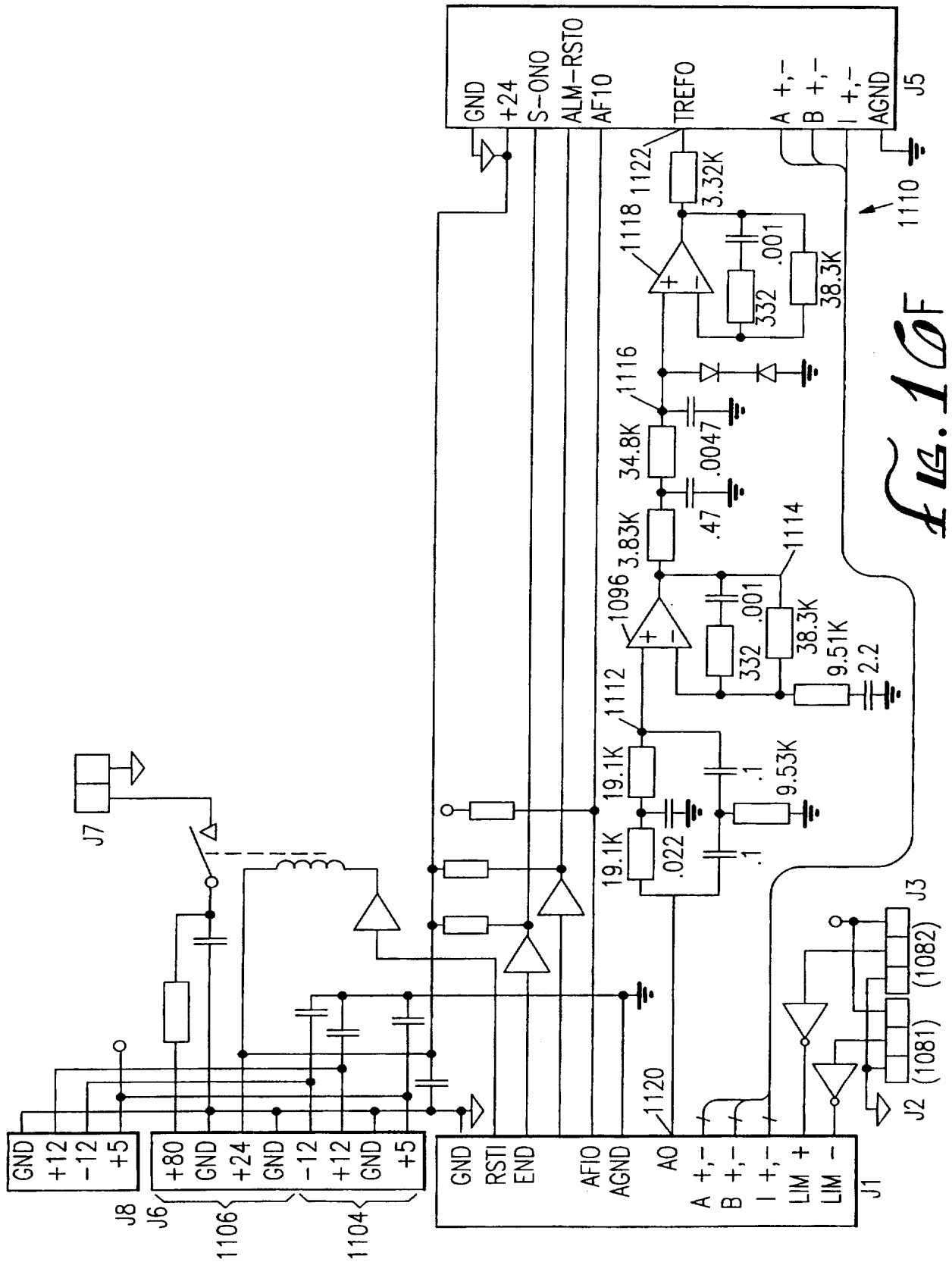

GND
+24
S-ONO
ALM-RSTO
AF10
TREFO
A +,-
B +,-
I +,-
AGND
J5
1110
1122
3.32K
1118
.001
332
38.3K
1116
34.8K
.0047
.47
3.83K
1114
1096
.001
332
38.3K
9.51K
2.2
1112
19.1K
.1
9.53K
19.1K
.022
.1
J7
GND
+12
-12
+5
J8
+80
GND
+24
GND
-12
+12
GND
+5
J6
1106
1104
GND
RSTI
END
AFIO
AGND
AO
1120
A +,-
B +,-
I +,-
LIM +
LIM -
J1
J3
J2 (1081)
(1082)

Fig. 16F

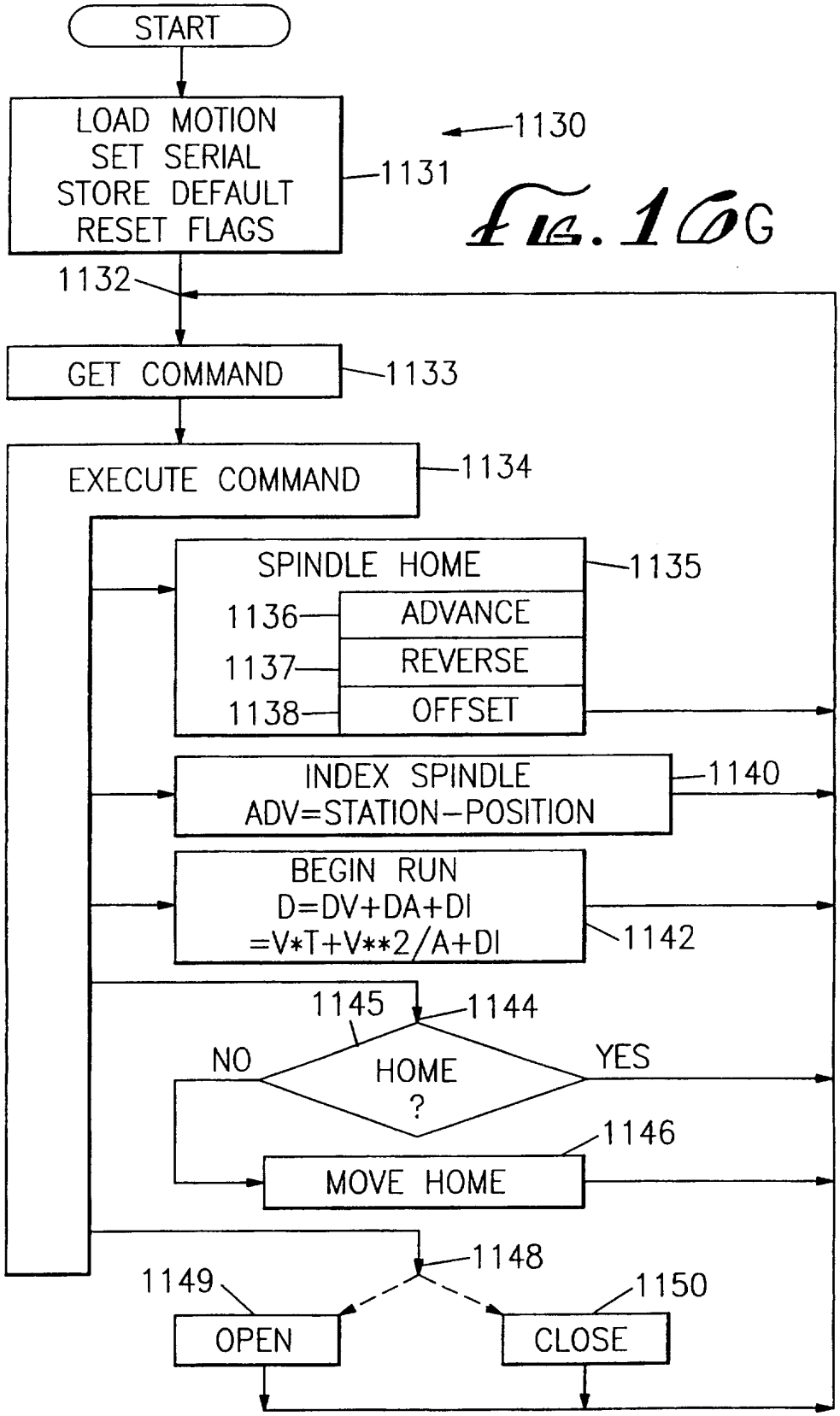

START
LOAD MOTION
SET SERIAL
STORE DEFAULT
RESET FLAGS
1130
1131
1132
GET COMMAND
1133
EXECUTE COMMAND
1134
SPINDLE HOME
1135
1136
ADVANCE
1137
REVERSE
1138
OFFSET
INDEX SPINDLE
ADV=STATION-POSITION
1140
BEGIN RUN
D=DV+DA+DI
=V*T+V**2/A+DI
1142
1145
1144
NO
HOME
?
YES
1146
MOVE HOME
1148
1149
1150
OPEN
CLOSE

Fig. 16G

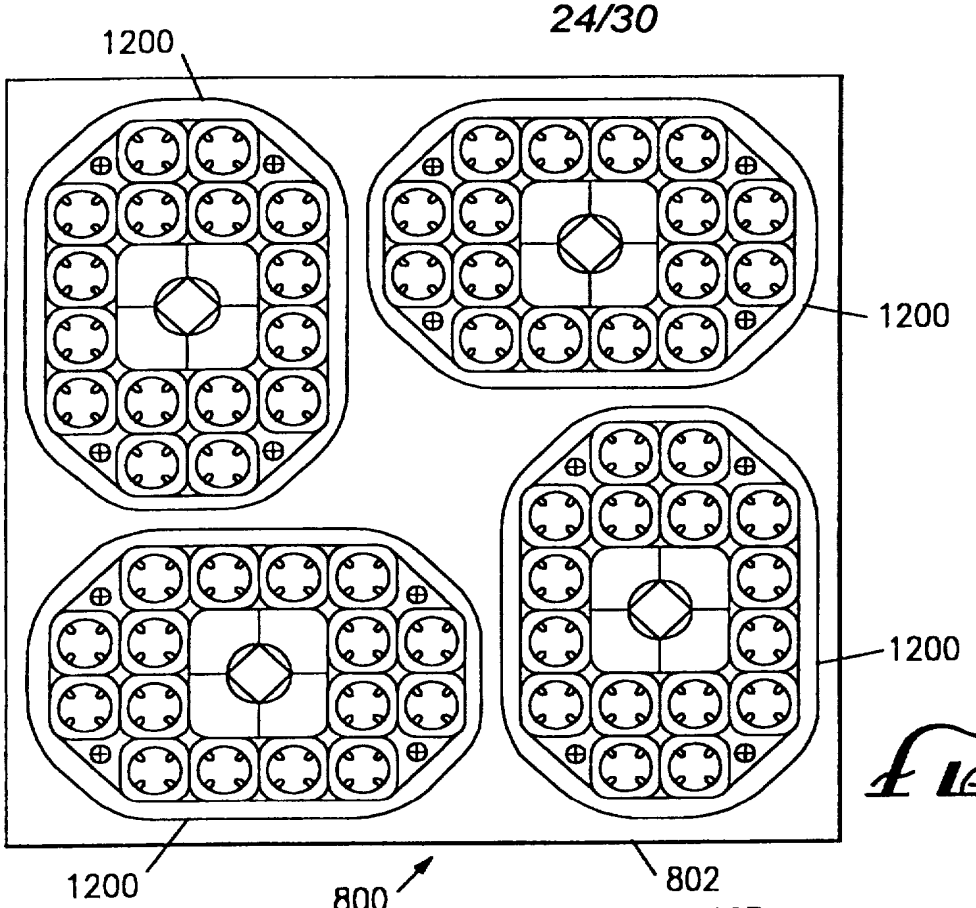
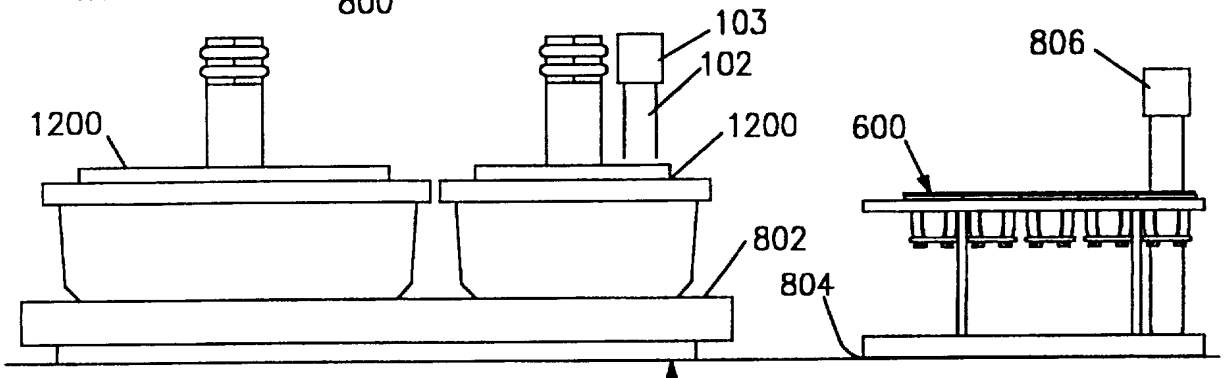


FIG. 17A



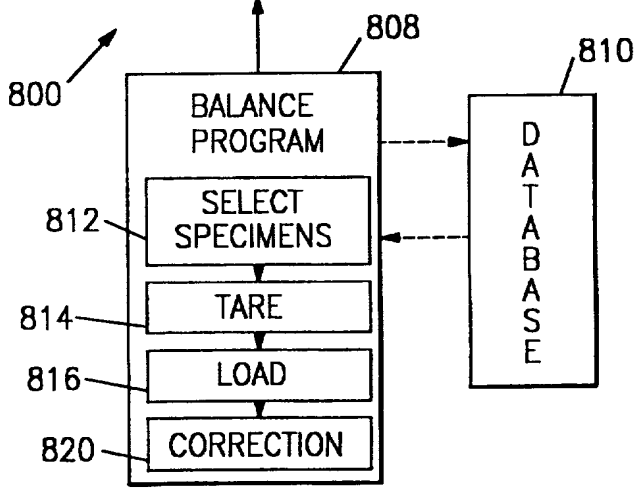


FIG. 17B

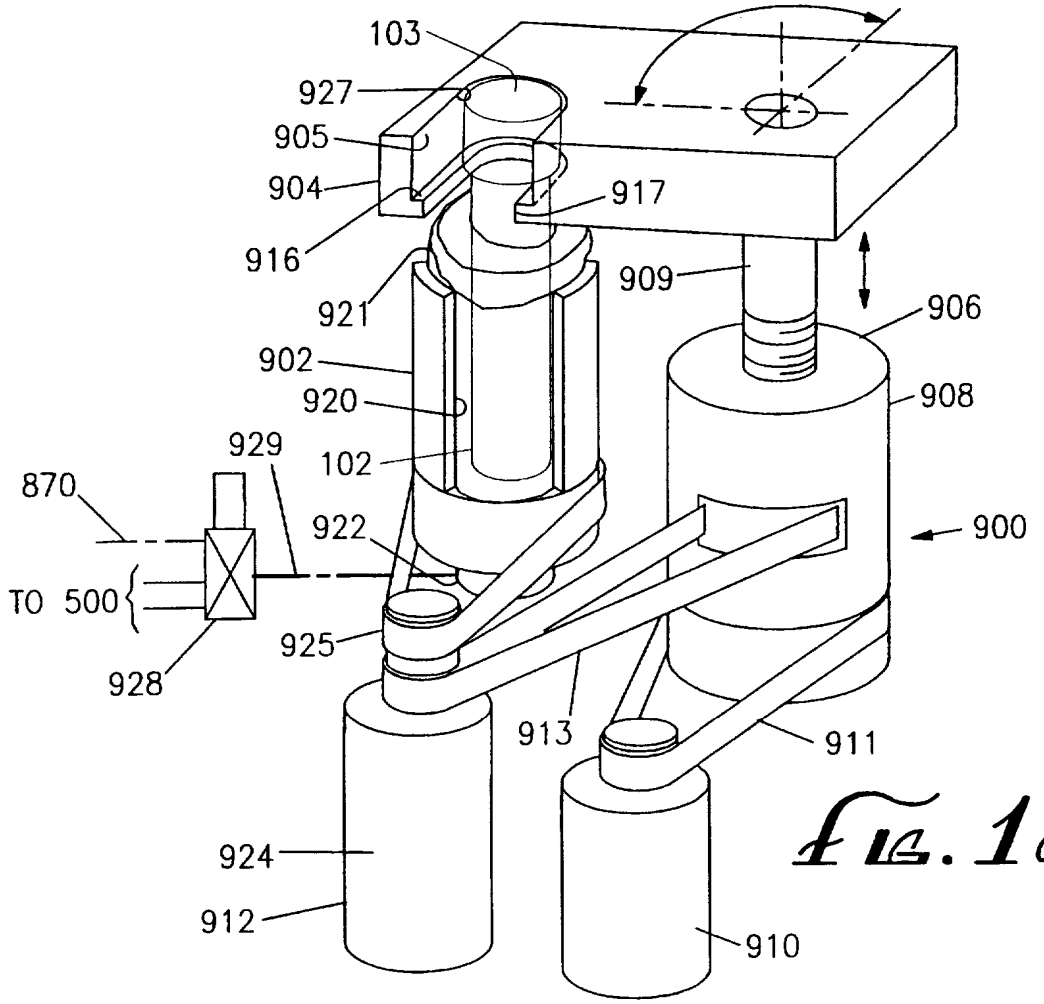


FIG. 18A

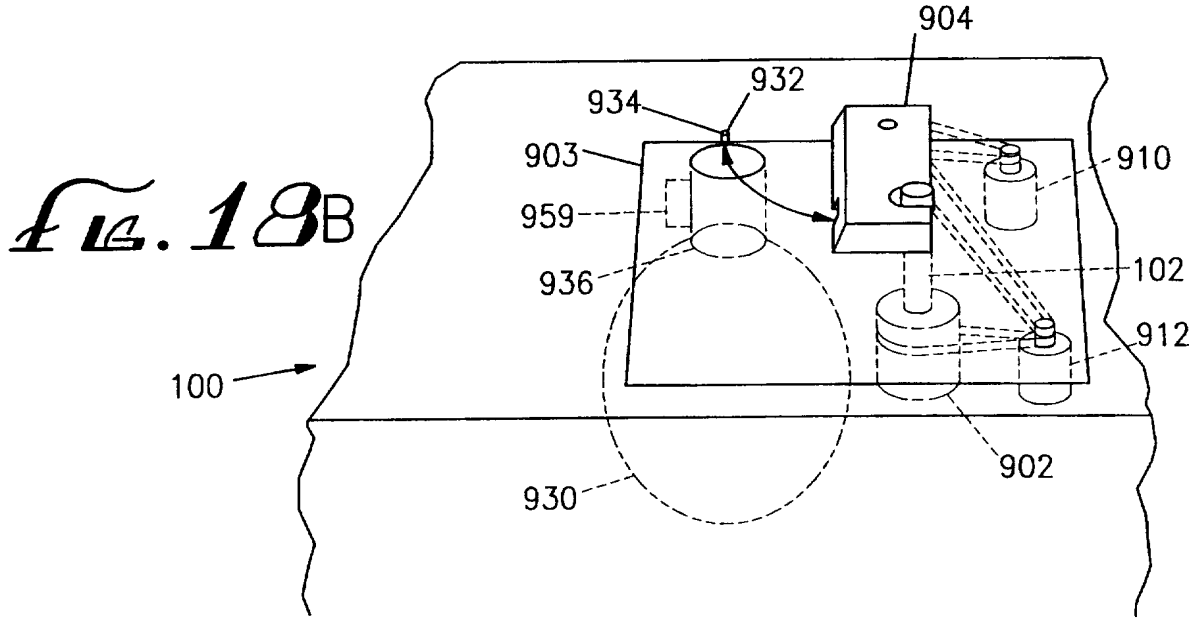


FIG. 18B

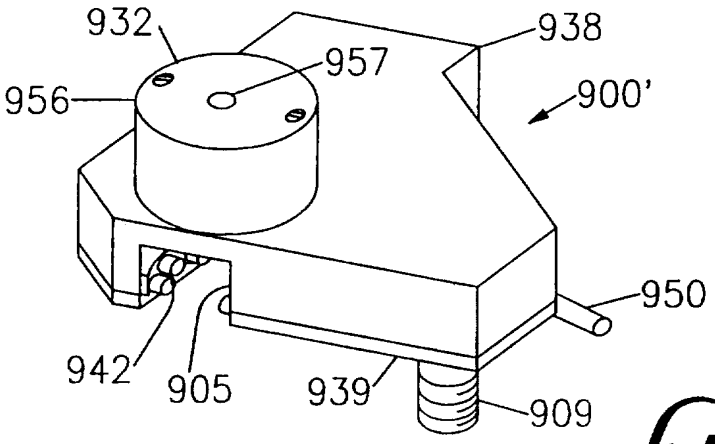


FIG. 18C

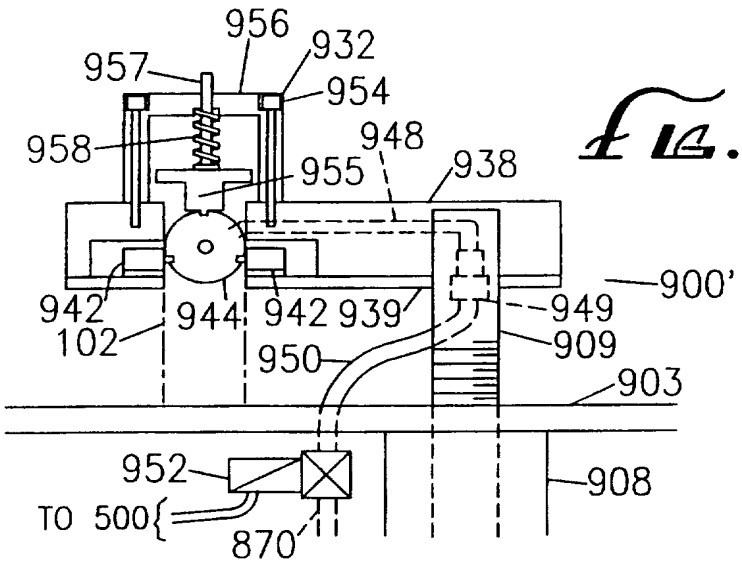


FIG. 18D

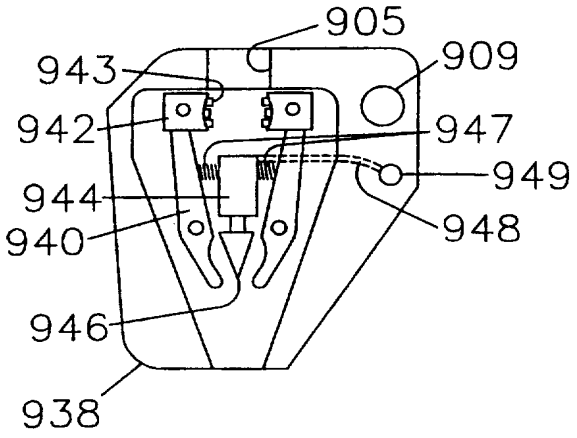


FIG. 18E

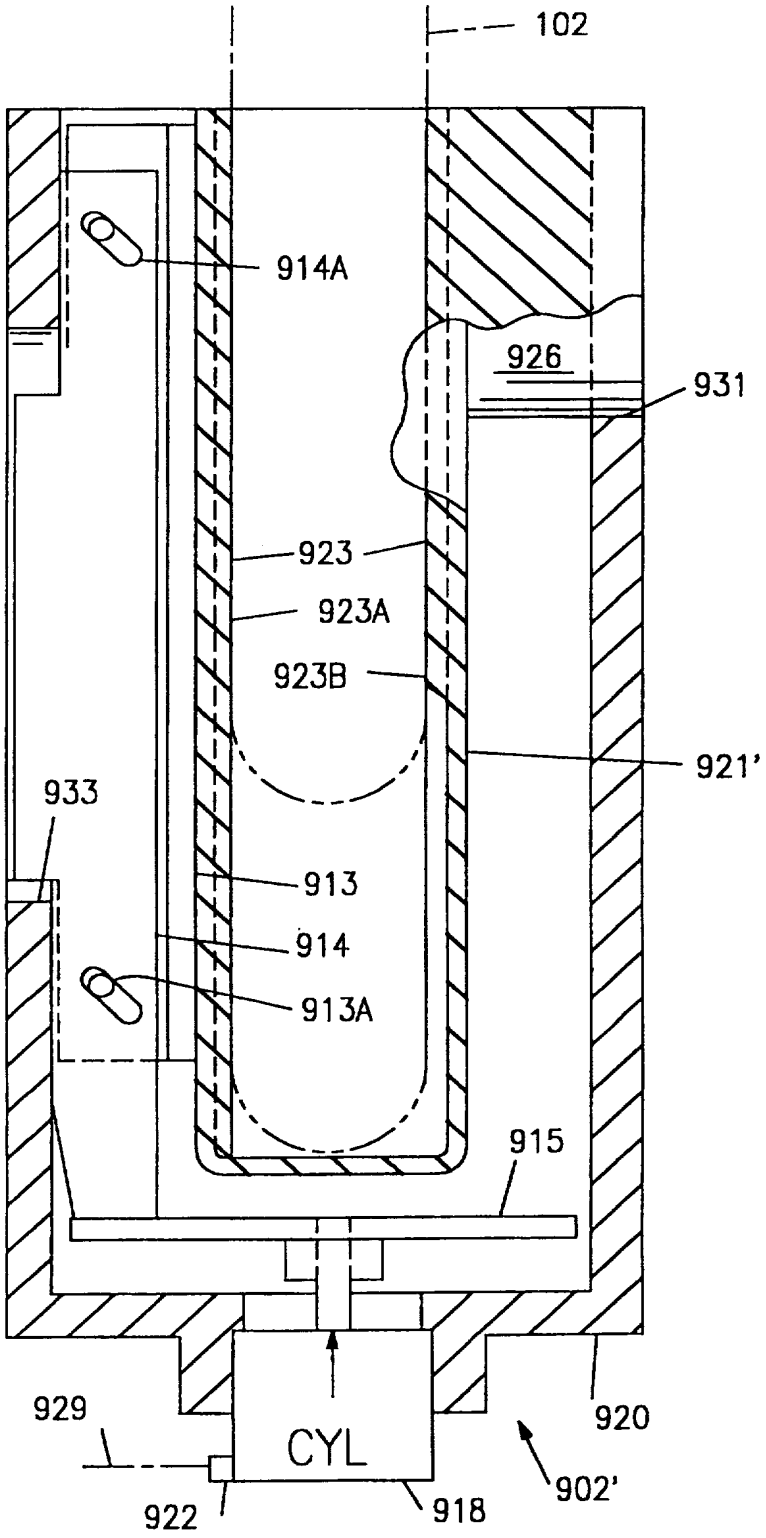

102
914A
926
931
923
923A
923B
921'
933
913
914
913A
915
929
CYL
920
902'
922
918

FIG. 18F

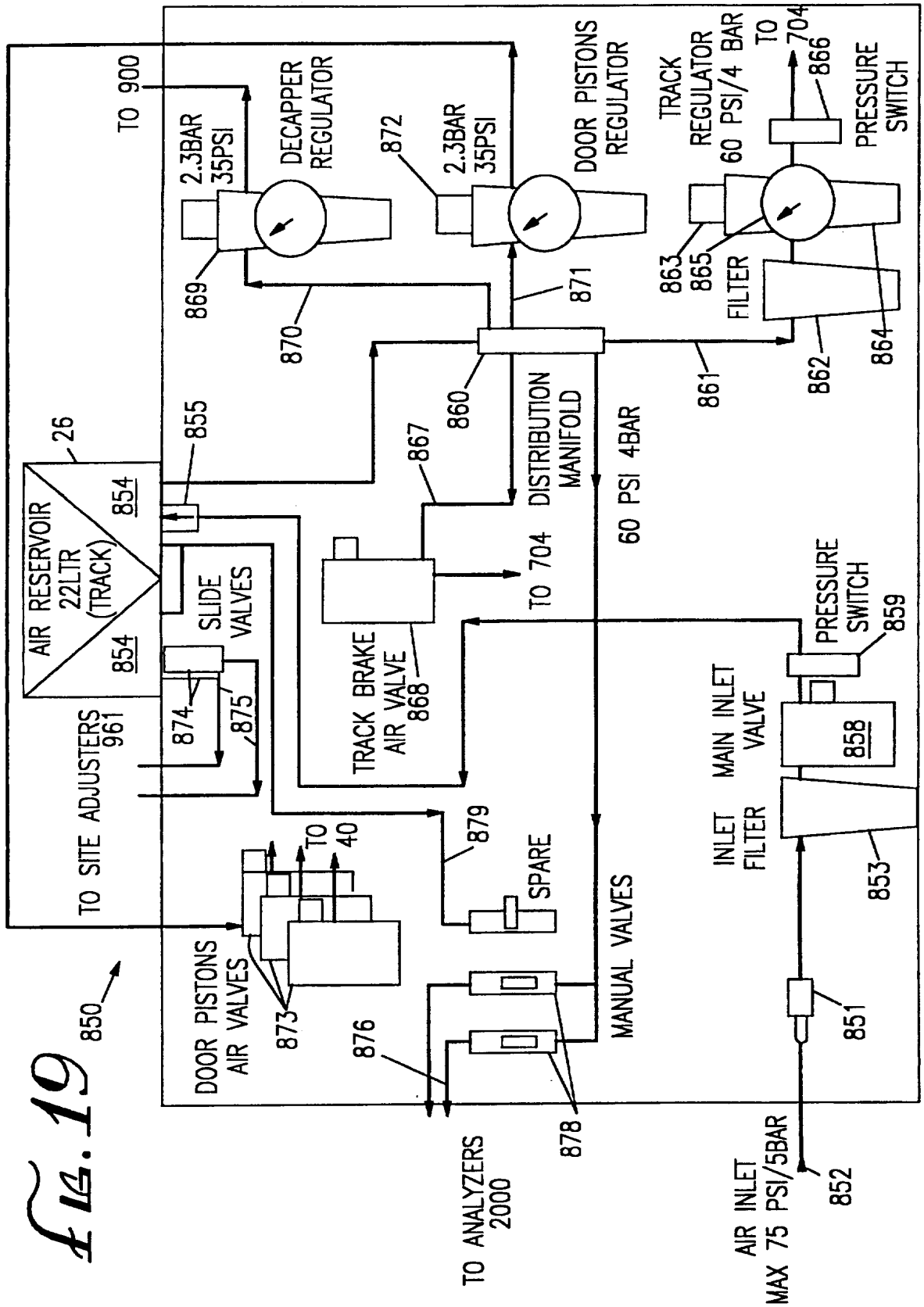

TO 900
2.3BAR 35PSI
DECAPPER REGULATOR
872
2.3BAR 35PSI
DOOR PISTONS REGULATOR
TRACK REGULATOR 60 PSI/4 BAR
TO 704
866
PRESSURE SWITCH
869
870
871
863
865
FILTER
862
864
861
860
855
867
DISTRIBUTION MANIFOLD
26
AIR RESERVOIR 22LTR (TRACK)
854
854
SLIDE VALVES
874
875
TO SITE ADJUSTERS 961
TRACK BRAKE AIR VALVE 868
TO 704
60 PSI 4BAR
PRESSURE SWITCH
859
MAIN INLET VALVE
858
INLET FILTER
853
879
TO 40
SPARE
MANUAL VALVES
DOOR PISTONS AIR VALVES
873
876
878
851
850
TO ANALYZERS 2000
AIR INLET MAX 75 PSI/5BAR
852

Fig. 19

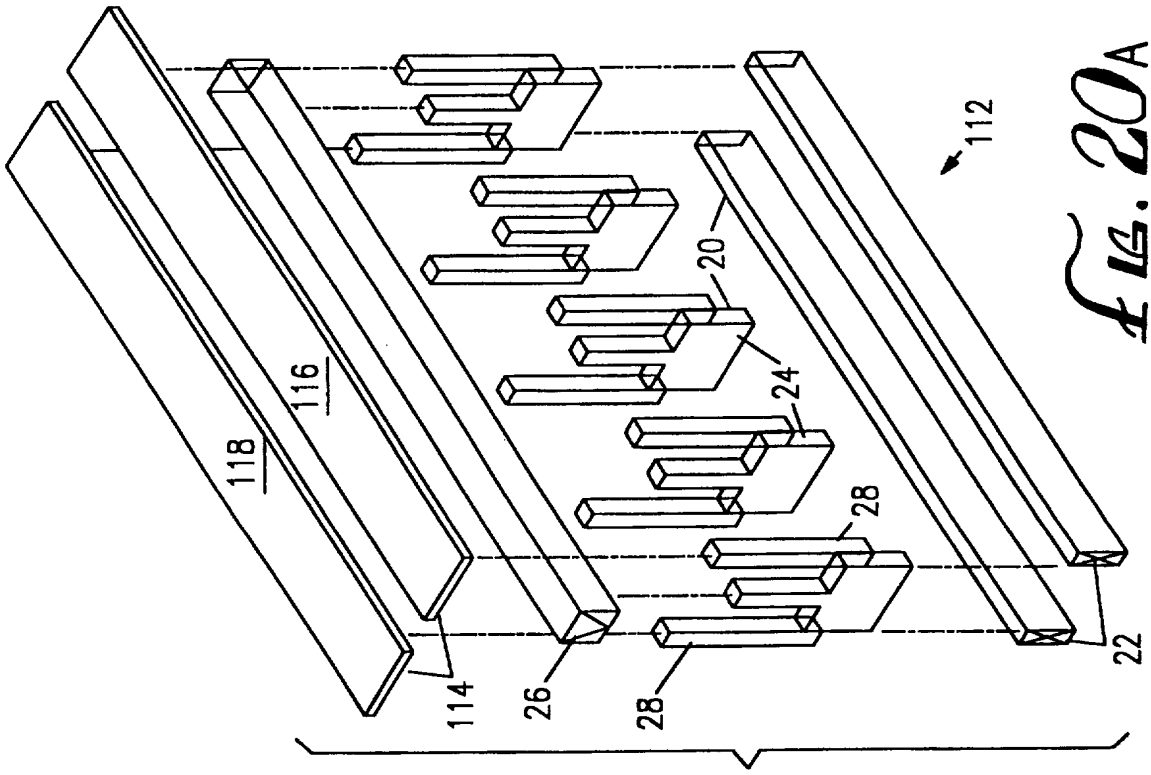


Fig. 20A

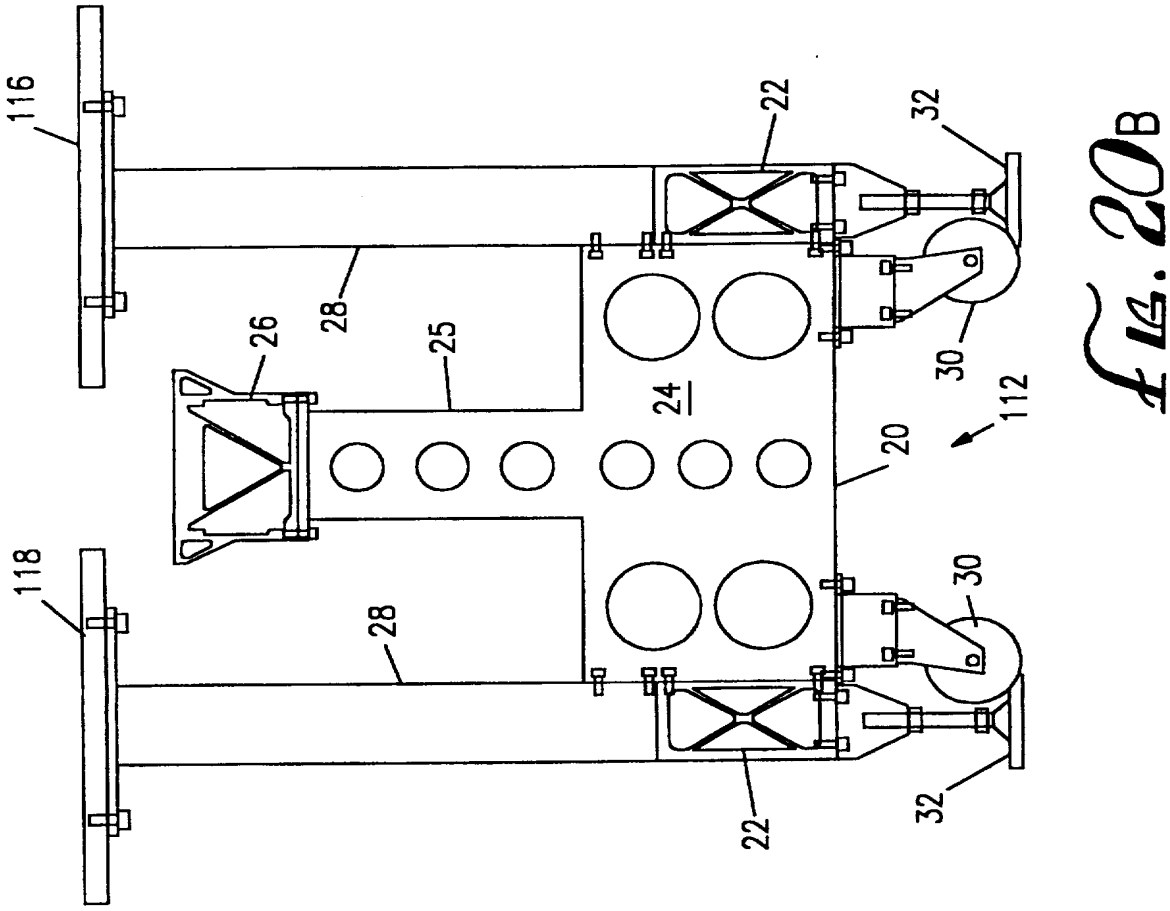


Fig. 20B

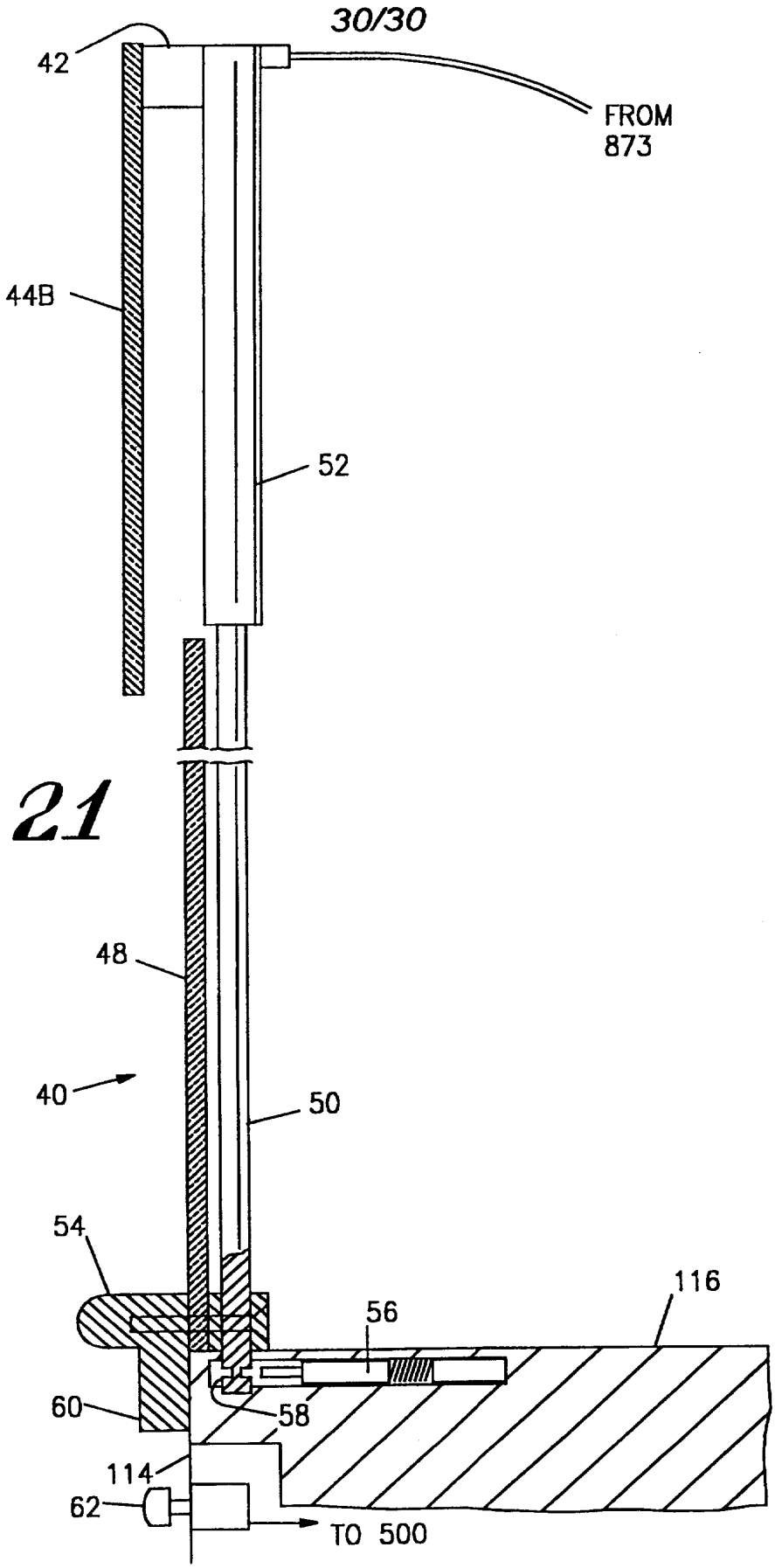


FIG. 21